New Simplified Thermal and HVAC Design Tools For Building Designers

by

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Summary

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Building designers are increasingly pressured to design buildings with high standards of energy efficiency, performance and comfort in the shortest possible time. Computer design tools have a tremendous potential for aiding designers in achieving the above design objectives. However, designers generally find the existing tools difficult to use. The potential of these tools is therefore still largely untapped, and the need for simplified design tools still exists.

Thermal efficiency of buildings and HVAC system selection are two areas that can greatly benefit from simple design tools. These aspects have a large influence on the socio-economic success of a building, but due to the complexity and time required for analysing the various options, they usually do not receive the necessary attention. A simplified thermal design and HVAC system selection tool was developed during this study to address this need.

Thermal efficiency of a building is largely determined by architectural design decisions made early in the design process. Detail required by existing simulation tools make them impractical for use by architects. Input complexity could however be significantly reduced for the new tool by applying Pareto's law of distribution. A sensitivity analysis was performed to identify the critical input parameters on which to focus.

An extensive verification study was performed to ensure that the simplification assumptions are valid and that the tool could be used with confidence. A South African building design rating

[1] Heating, Ventilating and Air Conditioning

scheme was also developed to further enhance the use of the tool. The scheme rates a building design depending on its HVAC system size requirements.

Ideally, HVAC selection also requires a detailed analysis to compare the various available systems. In practice, system selection is usually based solely on initial cost or the designer's experience. A simplified preliminary analysis can however be carried out by estimating system performance characteristics using expert knowledge. A preliminary rating and selection tool was developed by using a numerical ranking method as an expert system shell.

Selection criteria used as basis for comparing the various systems depends strongly on the building developer's requirements, and must therefore be taken into consideration. This is done by incorporating the whole design team in ranking the importance of attaining certain design goals. The selection tool thus further serves as a communication aid.

In order to demonstrate their function, the above simplified design tools were applied to design a hypothetical office building. Using these tools it was possible to perform an extensive building and system analysis without the need for detailed information. The required HVAC system size could be reduced by as much as 60% by applying the thermal analysis tool. The main benefits of the selection tool are that designers do not focus only on familiar systems, and aids designers in establishing the needs and requirements of the building developer.

It is believed that the new tools will contribute towards improving building efficiency and indoor comfort. This study shows that design tools need not be complex or difficult to use in order to be beneficial to designers.

Opsomming

Titel : New simplified thermal and HVAC design tools
Promotor : Prof. E.H. Mathews
Departement : Meganiese en Lugvaartkundige Ingenieurswese, UNIVERSITEIT VAN PRETORIA
Graad : Philosophiae Doktor
Sleutelterme : Voorlopige gebou ontwerp, Gebou termiese doeltreffendheid, Gebou energie klassifikasie, Lugreëlingstelsel seleksie, Rekenaargesteunde ontwerpsgereedskap

Daar word al hoe meer van moderne ontwerpers verwag om in die kortste moontlike tyd geboue met hoë energie effektiwiteitstandaarde en behaaglikheidsvlakke te ontwerp. Rekenaargesteunde ontwerpsgereedskap het die potensiaal om ontwerpers se taak te vergemaklik en dit met sukses af the handel. Die potensiaal word egter nog nie ten volle benut nie omdat meeste ontwerpers die gebruik van bestaande pakkette as veeleisend en moeilik ervaar. Daar bestaan dus nog 'n behoefte vir eenvoudige ontwerpspakkette.

Termiese effektiwiteit van geboue en die keuse van lugreëlingstelsel is twee areas wat kan baat by eenvoudige ontwerpspakkette. Die items het 'n groot invloed op die sosio-ekonomiese sukses van die gebou. Daar word egter nie altyd genoeg aandag aan die aspekte gegee nie omdat dit 'n komplekse en moeisame proses is om al die variasies te analiseer. 'n Eenvoudige termiese analise en lugreëling seleksie pakket was ontwikkel om in die behoefte te voorsien.

Termiese effektiwiteit van 'n gebou word grotendeels bepaal deur argitektoniese besluite. Bestaande analise pakkette is egter onprakties aangesien hulle baie detail benodig. Die nuwe termiese analise pakket is egter aansienlik vereenvoudig deur gebruik te maak van Pareto se distribusie wet. Die beduidende parameters was geïdentifiseer deur 'n sensitiwiteit analise uit te voer.

Die pakket is verder uitgebrei deur die ontwikkeling van 'n gebou ontwerpsklassifisering stelsel vir Suid Afrikaanse geboue. Effektiwiteit van die ontwerp word gegradeer volgens die grootte

van die benodigde lugreëlingstelsel. 'n Omvangryke verifikasie studie was gedoen om te verseker dat die nuwe pakket met sekerheid gebruik kan word.

Die keuse van 'n lugreëlingstelsel behoort ook gebaseer te wees op 'n breedvoerige analise om die toepaslikheid van die verskillende stelsels te vergelyk. In praktyk word stelselkeuse meestal gebaseer slegs op eerste koste of die ontwerpers se ervaring. Dit is egter moontlik om 'n voorlopige analise te doen deur stelseleienskappe en werkverrigting af te skat gebaseer op stelsel kennis. 'n Voorlopige stelselkeuse pakket was ontwikkel wat gebruik maak van bogenoemde tegniek en 'n eenvoudige numeriese klassifisering stelsel.

Stelselkeuse word sterk beïnvloed deur die vereistes van die gebou se ontwikkelaar en die' moet dus ook in ag geneem word. Dit word gedoen deur die hele ontwerpspan te betrek in die bepaling van watter vereistes die belangrikste is om te behaal. Stelsels word geklassifiseer ten opsigte van hoe goed hulle die vereistes nakom. Die pakket dien dus ook as 'n kommunikasie hulpmiddel.

Die gebruik van die nuwe pakkette was gedemonstreer deur hulle aan te wend in die ontwerp van 'n tipiese kantoorgebou. Dit was sodoende moontlik om 'n gedetailleerde gebou en stelselanalise uit te voer. Die benodigde lugreëlingstelsel kon met 60% verklein word deur gebruik te maak van die termiese analise pakket. Die voordele van die stelselkeuse pakket se is dat meer stelsels maklik vergelyk kan word en dat die kommunikasie tussen die kliënt en ontwerper verbeter.

Die nuwe pakkette het die potensiaal om 'n groot bydrae lewer in die ontwerp van energie effektiewe en behaaglike geboue. Die studie toon aan dat ontwerpspakette nie kompleks of moeilik bruikbaar hoef te wees nie.

Contributions of this study

The following main contributions were made by this study:

- A new thermal design tool was developed for use by architects. The tool addresses the need for incorporating architects in designing new energy efficient buildings. Its development followed an innovative approach towards reducing the input complexity hampering the use of existing thermal design tools.

- A new building thermal efficiency rating scheme was developed for South African residential and office buildings. Using this rating scheme designers can quickly compare and evaluate the efficiency of their design without the need for a detailed analysis.

- The thermal design tool was extensively verified in order to establish confidence and credibility in its use.

- A new preliminary HVAC selection tool was developed. It combines the simplicity of numerical ranking methods with the proficiency of expert systems. It also addresses the need for better communication between the different design team members.

- In the long run, the use of the new tools could potentially contribute greatly to the design of new energy efficient buildings without further complicating the existing design methodology.

Preamble

The main body of the thesis consists of eight chapters. Each of these chapters, with the exception of Chapter 8, is written in the form of a journal article including its own abstract, introduction, main body, conclusions and references. Each chapter therefore can be read on its own or in the broader context of the study. To improve readability, all appendices are included at the end of the document.

In Chapter 1 the needs and trends in building and HVAC design tools are identified. This formed the basis on which a new thermal design tool for architects and a simplified preliminary HVAC selection tool was developed in Chapters 2 and Chapter 5 respectively.

In Chapter 3 an extensive verification study was performed in order to verify that the simplification assumptions are valid, and to establish confidence in the use of the new thermal design tool. To further facilitate the use of the tool, a new South African residential and office building rating scheme is presented in Chapter 4.

In Chapter 6 the necessary system rating factors are provided for the preliminary HVAC selection tool.

The application of the two simplified design tools was demonstrated in Chapter 7, and Chapter 8 presents recommendations for further work.

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Chapter 1 Needs and Trends In Building and HVAC System Design Tools

Modern building and HVAC systems are required to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance. Economical considerations and environmental issues also need to be taken into account. These factors, as well as an increase in design liability and a requirement to complete designs quickly, have placed unprecedented pressure on designers. Computers are seen as an important design tool that can reduce some of the strain. This chapter provides a short overview of the use of computers, and advances made in software development in the building and HVAC field.

The trend in the development of new computer tools is towards integrated and expert design tools. This is a big step towards optimal, energy efficient building design. However, it was found that only a few designers make use of these tools. This chapter also identifies the reasons for this and highlights some of the aspects that need attention. One of the main reasons is that in general there is a big difference in what designers require and what is available. Complexity of the tools seems to be the biggest stumbling block. The remainder of this study is based on these findings.

1.1 INTRODUCTION

Modern buildings and their Heating, Ventilation and Air-conditioning (HVAC) systems are required to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance. This must be accomplished within certain constraints.

Typical constraints are economical considerations such as installation and operating costs, ease of maintenance, flexibility, and spatial requirements, as well as environmental issues such as the reduction and banning of certain refrigerants and noise pollution [1,2,3,4,5]. Consequently, building and HVAC design is a complex task consisting of various interactive factors that requires experts from different disciplines. According to Kennington [6] this complexity is one of the main reasons why the building industry has made little progress in improving energy efficiency.

Researchers believe that it is possible to obtain savings of around 30 % through the use of new and better design techniques and tools. Most of these savings are based on an integrated system design approach. This consists of finding the optimum interaction between the various factors and their constraints [7,8,9,10,11].

In order to make a living, designers are usually required to complete their designs quickly. This leaves hardly any time for optimising their design. In the last decade designers have therefore increasingly turned to computer design tools. Numerous design applications have been developed for this purpose. Most of the widely used software only focuses on one or two design aspects, such as load calculations, energy consumption estimation, duct design, pipe design, etc. [12]. Existing software therefore lacks the required continuity and integration to be truly useful in optimal design [6,11,13].

Researchers have only recently begun to look at integrating different design tools. This integration can be grouped into two main, but overlapping, categories. The first category deals with the development of software dedicated towards integrating HVAC system and building thermal simulation. The second category focuses on the transfer of data between design applications. This is done through the use of a central database.

These developments have a tremendous potential for saving energy. To be truly effective however, these tools must be widely accepted and used by the design community. Currently, designers are finding it difficult to exploit even the basic computer tools available to them. Complexity of existing tools and their integration into the design process seem to be the biggest barriers. New tools must therefore be designed in close co-operation with designers so that their requirements can be addressed.

A need therefore exists for design tools that are user-friendly and easy-to-use. These tools should be able to provide answers quickly and calculations should require the minimum amount of input so as to be useful during the initial design stages. Based on this, they should be able to give quantitative answers regarding the influence of design decisions. These elementary design tools must further be able to transfer data to more complex and detailed design tools. Detailed calculations can then be made after the initial design has been finalised.

1.2 ECONOMIC IMPORTANCE OF BUILDING DESIGN

Buildings form an important part of the modern lifestyle. It is not surprisingly also one of the largest industry sectors worldwide [6,11]. Buildings, especially commercial buildings, are further one of the biggest consumers of energy. In developed countries, buildings account for between 30 and 40 % of the energy consumed [14,15]. Another alarming fact is that their energy consumption seems to be on the rise.

A report of the American Council for an Energy Efficient Economy showed that commercial buildings had the highest growth in energy consumption during the mid 1980s [16]. This corresponds with data adapted and corrected for inflation by Kreider and Rabl [5], as shown in Figure 1.1.

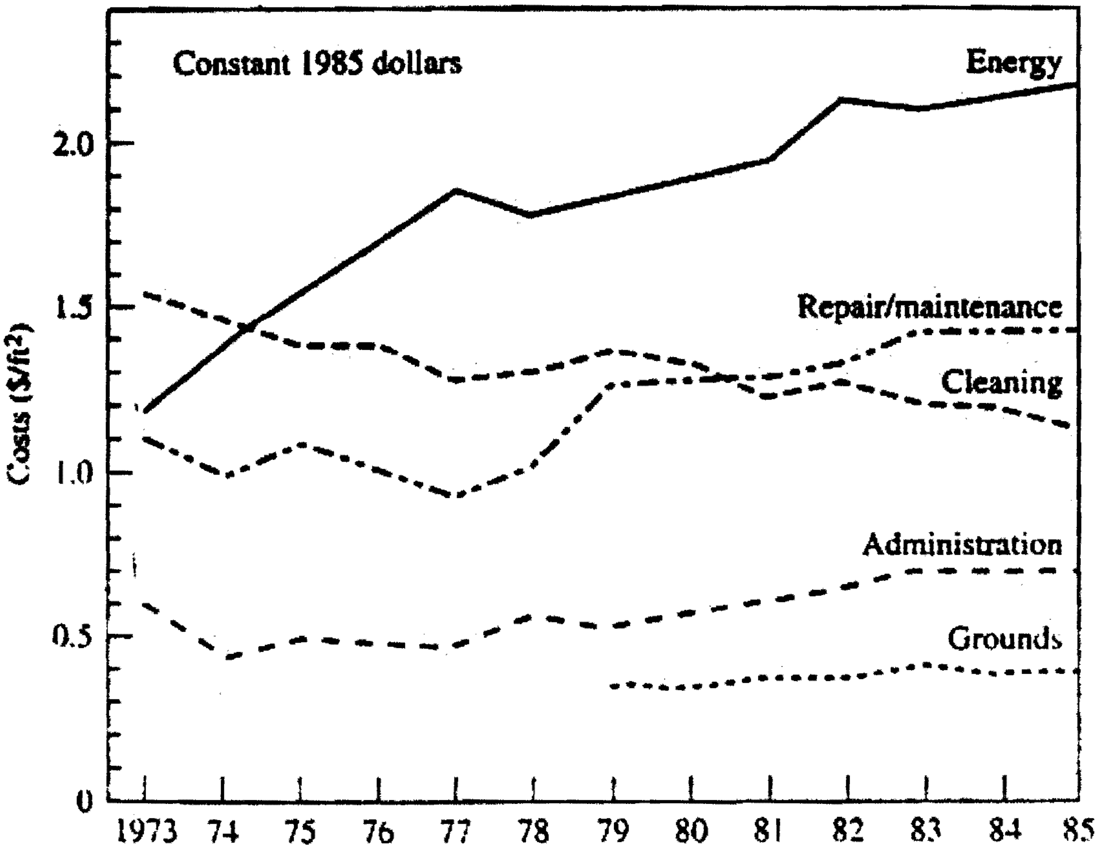

Figure 1.1 – Average office building operating cost per floor area corrected for inflation $\$1/ft^2 = \$10.76/m^2$ [5]

In general most of this energy is used to maintain acceptable comfort levels within buildings. Of this, lighting and HVAC systems form the largest consumption items. Studies indicate that air-conditioning is responsible for between 10 and 60 % of the total building energy consumption, depending on the building type [17,18].

Maintaining high standards of indoor comfort is an economically sound goal. Research shows that indoor comfort and productivity can be linked [19,20]. These studies indicate that the economic gain with a small increase in productivity outweighs energy savings obtained by reducing the indoor comfort levels. A balance between energy efficiency and indoor comfort must thus be obtained.

Energy efficiency and comfort further impacts on the life-cycle cost of the building. A building with an ineffective HVAC system or high running cost is also unlikely to be leased or sold easily. Figure 1.2 illustrates the effect that the different role players have on the building life-cycle cost. The client's brief, if very complex, has an enormous impact on the cost. However in general the architect/engineering team has the greatest influence [21].

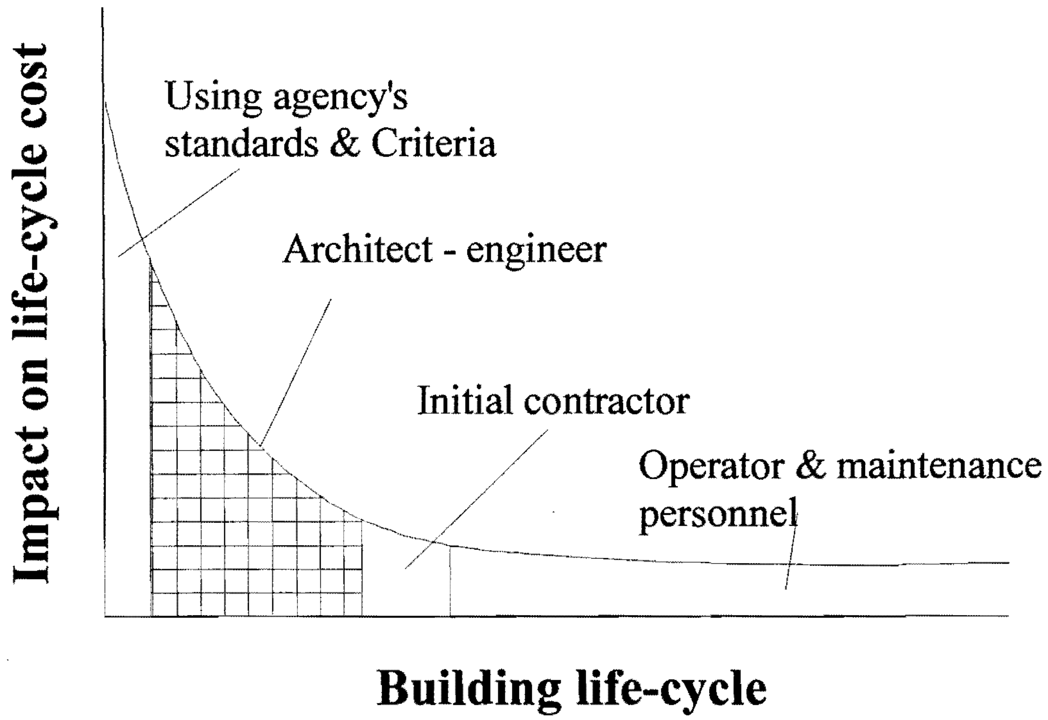

Figure 1.2 - The impact different role players have on building life cycle cost [21].

The importance of architectural and engineering design decisions is further compounded by the relatively long life of buildings. The replacement cost of the total value of buildings in the US during the 1980s was estimated to exceed the Gross National Product (GNP) by 20 to 40% [5]. Existing buildings can thus obviously not be replaced too often. It is therefore not surprising that the design of comfortable, energy efficient buildings is receiving a lot of attention. Research in this field tends to be focused on computer software applications aimed at reducing energy consumption.

1.3 COMPUTER APPLICATION IN DESIGN

It has long been known that computers are better at performing repetitive calculations rapidly, accurately, and tirelessly. Modern design tools are however required to do more than this [22]. Typical requirements of new design tools are to:

- suggest possible solutions,
- compare various designs,
- optimise design solutions,
- analyse economical aspects,
- size the various components,
- compute the performance, and
- verify compliance with, and draw attention to possible conflicts with local regulations.

The availability of relatively cheap and powerful desktop computers has opened up a new treasure chest of design capabilities. Small consulting firms now have access to computing power previously accessible only to research institutions and large companies. This, coupled with enhanced graphic capabilities, has drastically increased the use of computers. A wide variety of design applications are currently available for HVAC and building design. They range from complicated finite element applications to simple electronic nomographs. Their typical applications can be classified into the following groups [22,23]:

1.3.1 Building thermal and energy analysis

These applications are used to calculate the peak heating and cooling loads of buildings. This in turn is used to determine the required HVAC system size. They vary in complexity and accuracy from simple steady-state calculations to finite difference methods. ASHRAE [23] lists what factors to take into consideration when selecting such a design tool. These packages form the link between architect/engineer, buildings thermal shell and system size.

Some of the advanced applications incorporate energy calculations and estimation of installed HVAC and lighting systems. These applications mostly originated during the energy crisis were they formed part of government sponsored research into energy efficient building design, as well as energy audit and retrofit programs. Most of these incorporate some sort of pre-specified HVAC systems. They are however mainly used by research and/or government institutions.

1.3.2 Equipment selection and simulation

ASHRAE [23] identifies three types of equipment related programs. The first group consists of equipment selection programs. These programs are essentially electronic catalogues. Given certain design criteria, these programs will locate a suitable component model number. They are usually distributed by equipment manufactures.

The second group consists of equipment optimisation programs. These programs display a range of possible equipment alternatives. Given design criteria, the program aids the designer in finding the best solution.

The third group consists of equipment simulation programs. They are used to calculate the full- and part-load performance, perform system diagnostics, and for training purposes. Simulation programs can also closely be linked to the above energy analysis programs and integrated computer applications.

1.3.3 System design and sizing

A large number of programs are available for designing and sizing HVAC systems. The most prominent of these are duct and piping system design programs. There are basically two main needs in ducting and piping design, namely sizing and flow distribution. Sizing and system selection forms part of any new system design while flow distribution is required for calculation of flow if the duct sizes and fan characteristics are known.

Some of the programs also perform heat gain calculations, produce a bill of quantity, and perform stress analyses. Duct and pipe sizing are closely related to drafting tools. Quite a few of these programs can therefore be used in conjunction with computer aided design packages.

1.3.4 Computer-aided design (CAD)

Computer-aided design (CAD) systems are tools used for drafting and to some extent as a component database. Drafting forms an important communication media. It conveys pertinent information such as the physical size, as well as the relation of various components to one another. This, coupled with the component database, gives designers a powerful tool for conveying their ideas to the rest of the design team.

One of its most important benefits is that drawings can quickly be created or changed. Small changes do not require a completely new set of drawings to be made. Some of the more advanced CAD programs allow the user to extract material and component data for reports and specifications.

1.3.5 Acoustic calculations

Acoustic analysis is another design area that has benefited from the computer age. According to ASHRAE [23], the analysis of noise in HVAC systems is straightforward. It is however laborious due to the amount of computations involved.

1.3.6 Building regulation and code analysis

These software packages form part of a new generation of design aids. They are especially indispensable in countries with strict building regulations and codes. Designers use them as a quick and easy method for determining whether a new building complies with local codes and regulations. Most of the building regulations and codes analysed by this kind of software are energy related. A typical application is checking whether a proposed construction has a lower overall heat transfer coefficient (U-value) than a specified value.

1.3.7 Administrative and productivity tools

These tools typically consist of word processing, spreadsheet, project scheduling, and accounting applications. Administrative and productivity tools, along with CAD applications, are of the more popular computer tools used by architectural and engineering firms [24].

Except for spreadsheet applications, these tools are not directly linked to the actual building design. They are more likely to be used for the day to day management of projects and company administration.

In summary, it can be seen that there is a wide range of possible applications for computers in the building design field. Converting existing mainframe computer applications so that they can be used on PC based computers, and providing existing programs with user-friendly interfaces are some of the areas receiving a lot of attention. New development in this field tends to be toward integrated building design tools and knowledge-based systems.

1.4 INTEGRATED BUILDING DESIGN TOOLS

Integrated building design systems (IBDS) are seen as the next generation of building design tools. There are two main driving forces behind this development. Firstly, existing software lacks the capability to deal with the complex nature of building design. Secondly, there exists a need for sharing information and for rapid feedback between the various design professions [6,7,11].

By integrating the design tools, a better analysis can be made of the effect that various sub-components will have on the building as a whole. Integrated tools will also allow rapid feedback of analysis results to the various design disciplines. The influence of different design decisions can therefore be investigated quickly. A better understanding of the dynamic component interaction and improved communication will enhance the chances of reaching an optimal design solution.

It is believed that integrated design tools will lead to more energy efficient and environmentally friendly buildings. Two different but overlapping categories of integrated tools can be identified. The first kind focuses more on the physical interaction and analysis between different sub-systems and the second kind focuses more on the exchange of data and information between different building design disciplines.

The basic idea behind the second category is to provide designers with a "toolbox" filled with different design software. These tools all share a central database reducing the need for entering the same data into different applications. Ideally, design tools of the first category will form part of the "toolbox" of the second category. The literature however refers to both types as integrated design tools. They will therefore be discussed separately in more detail.

1.4.1 Integrated building and sub-systems design tools

Ever since the energy crisis of the seventies, researchers have discovered that the efficiency of a building can closely be linked to the interaction of its sub-systems. They found that there is a huge potential for energy savings when closely related system interaction is optimised. Probably the best example of this is the interaction between the building envelope, HVAC system, and its controller.

Numerous energy analysis and system simulation tools have been developed as so-called "integrated" design tools. Some of the tools available include DOE-2 [25], AXCESS[26], COMTECH[27], HAP E-20[28], BLAST[29], TAS[30], TRACE[31], HVACSIM+[32], TRNSYS[33], and QUICKcontrol [34].

The main benefit of these tools is that they give the user an indication of the expected energy consumption of building and HVAC system combination. Different HVAC and control systems or energy savings strategies can be compared and analysed. Combined with economics analysis, they are powerful tools in selecting the best solution for each building. Another benefit of the economic analysis is to convince building developers to invest money in energy savings schemes.

Most of the integrated design tools are difficult and cumbersome to use, and cater more for the research community. Another drawback is that they can require long calculation times, which is unacceptable for use in design. It should also be noted that most tools are not fully integrated [35]. They do not solve the building and HVAC system simultaneously at each time step. This means a real-life situation is usually not correctly modelled [8]. There are however a few, for example QUICKcontrol, that perform an integrated simulation and are still relatively easy to use.

It is hoped that improvements in computing power and more user-friendly operating systems like Windows® will help to make this type of program more accessible. Other practical problems, such as the difficulty of adding or adapting models and numerical instability must also be addressed. Organisations that specialise in building and system simulations and act as consultants for building designers, is one solution. Another is to use systems, which uses a standard for data and information exchange. Users can therefore easily adapt models to suit their needs.

1.4.2 Integrating building design tools

Computer tools already support many of the different building design discipline functions. The information required by these tools frequently overlaps. Current available software however lacks the ability to transfer data between different tools or design disciplines. This is seen as a major obstacle in efficient building design. In order to solve this problem, the concept of integrated building design systems (IBDS) has emerged.

There are two approaches followed in the development of IBDS. The first is the project-driven approach. This is based on pre-specified design scenarios and data requirements. These systems are therefore limited in scope and application. The second, and more popular, is the object-driven approach. The basic idea of the object-driven approach is to use a central database.

The central database contains all the information required to describe the different design objects. This information is structured according to an internationally accepted standard such as the ISO Draft International standard 10303 [36]. New software tools, based on the same standard, can easily be added. This method of data transfer has it origins in the Computer Integrated Manufacture (CIM) community.

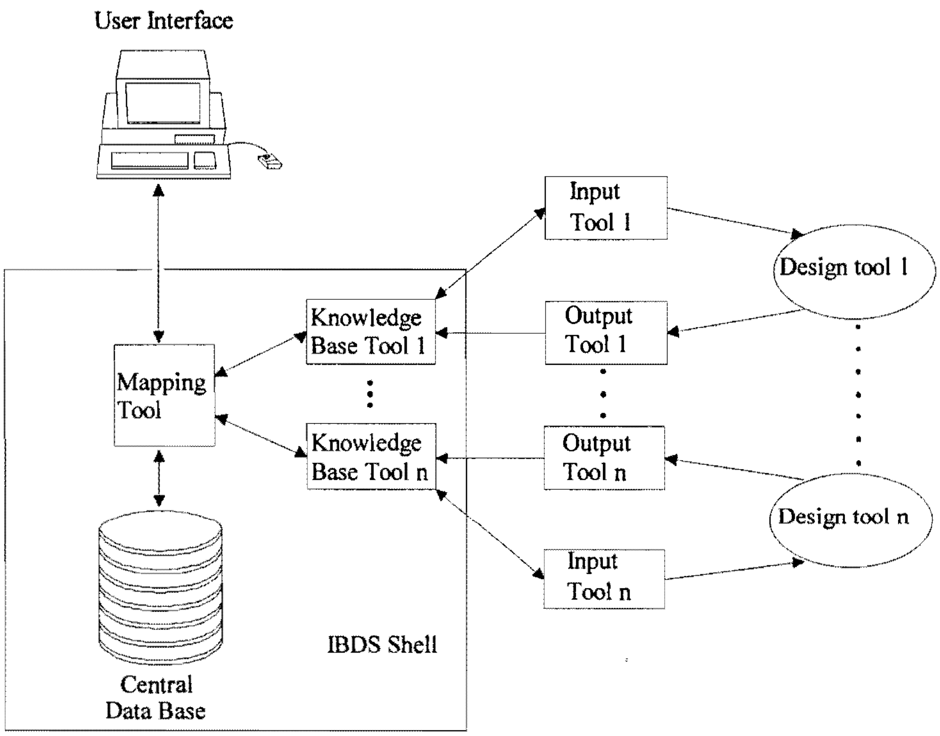

Figure 1.3 – Typical IBDS structure (Adapted from [13])

A mapping tool converts and channels the available information so that the different design tools can access it. This method of transferring data allows for the use of existing software, without the need for significant reprogramming. An added advantage is that designers still use tools that they are familiar with, reducing the need for extra training.

IBD systems are further structured so that any tool can be accessed at any time. Information required by a tool, which is not yet available, can be estimated or added by the designer. Information and results will automatically be updated as improved data is obtained or calculated from a different tool. This open structure does away with rigid or prescriptive design paths that can stifle design creativity.

Some examples of IBD systems are COMBINE (Computer Models for the Building Industry in Europe) as part of the ECjoule program [6,7], AEDOT (Advanced Energy Design and Operation technologies) for the U.S. Department of Energy [37], IISABRE (Intelligent Integrated System for the Analysis of the Building theRmal Environment) developed by the

HVAC Division of Tsinghua University [38], and BDA (Building Design Advisor) developed by the Lawrence Berkley National Lab [39].

The use of a central database has some practical problems. Different design professionals are usually contracted from various consulting firms. Communication between designers customarily consists of regular meetings and the exchange of paper drawings. A survey of thermal simulation tool users further indicates that there is nothing to suggest that electronic communication between firms fits the way they would like to communicate in the future [40]. Updating and exchanging database information is thus hampered.

Improvements in the World Wide Web may in the long run benefit the exchange of electronic data. There will no doubt still be some compatibility problems if designers us different IBD systems. It is therefore believed that these systems will mostly benefit building researchers or other multi-disciplinary institutions.

1.5 EXPERT SYSTEMS

Most of the existing "design tools" perform calculations, simulations and quantitative analyses. It is still up to the designer to present a design solution to be evaluated. They are consequently seen as Decision Support Systems (DSS) rather than true design tools [23,41]. Expert systems or Knowledge Based Systems (KBS) on the other hand are capable of making decisions similar to those made by human experts.

These systems use heuristic strategies, developed by humans, to solve specific classes of problems [42]. Decisions and suggestions made by these systems are based on facts, if-then rules, and models. The rules and information used by the program are gained from various experts in the field. These programs can thus be seen as an attempt to capture the knowledge and reasoning of human experts. The architecture of a typical expert system is shown in Figure 1.4.

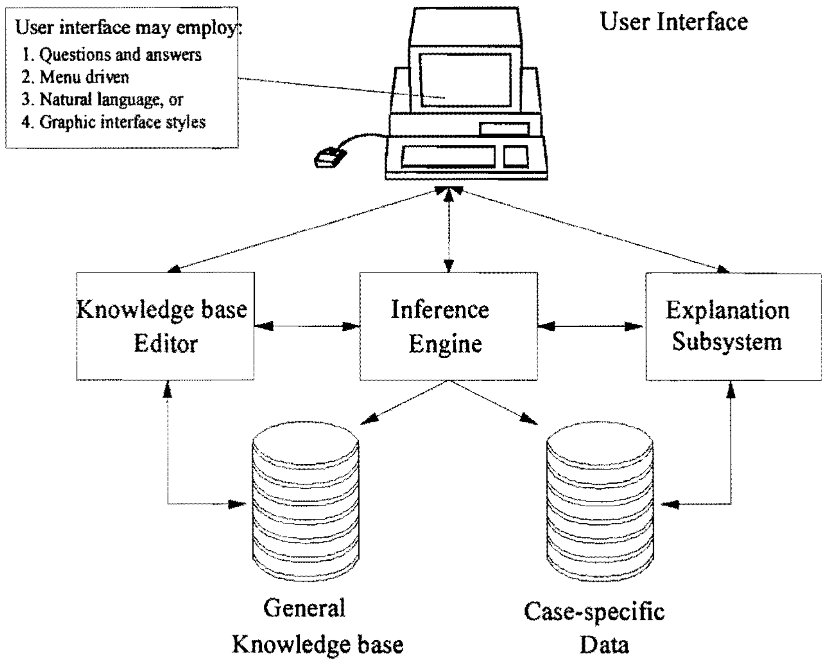

Figure 1.4 – Architecture of a typical expert system (Adapted from [42]).

The system gains problem specific information via the user interface. The inference engine processes this information. The if-then rules and known facts are applied to determine a solution for the problem at hand. These systems are also usually open for inspection. The user may at any stage inquire as to the logic or reasoning followed by the tool. These queries are handled by the explanation subsystem.

Unlike a human expert, these systems cannot learn from experience. Expert systems are limited to the heuristic rules programmed into the general knowledge base. Reasoning and decision making capability are therefore fixed to the information explicitly defined in the knowledge base. Decisions made by these systems are further only as effective as the experts used to compile the rules.

Creating the knowledge base is another problem facing developers of these systems. Gaining and extracting knowledge from human experts and defining it in "if-then" rules is not a simple task. Experts are frequently unaware of the knowledge they have and of the way in which they use it. An additional aspect to take into consideration is that experts may have different and sometimes conflicting sets of rules.

Another inherent trap of using expert systems is that these tools can soon become outdated. This is due to continuous development in the field of building and HVAC systems. Certain rules may become invalid as advances in technology are made and new techniques develop. They also tend to promote building uniformity. This is undesirable from an aesthetic and individualistic perspective [43].

Hall and Deringer [44] provide an extensive overview of research and development done on KBSs in the HVAC field. Typical applications of knowledge-based systems in building and HVAC design are (as adapted from [23,44,45]):

- Building envelope design [46, 47],
- structural design [48],
- building layout design [45],
- system diagnostics [49],
- system selection [50,51],
- control and monitoring [52], and
- building regulation and design code testing [53].

1.6 PROBLEMS WITH EXISTING COMPUTER TOOLS

There are huge design efficiency and energy savings benefits to be gained by using computer tools. This potential is however still largely untapped. Few building designers exploit the full potential of the building design and simulation tools available to them. According to McElroy [54], the use of computers in building design tends to be restricted to CAD and steady state calculations. This lack of widespread use can be attributed to various inherent problems with existing tools.

The main problem identified from the literature is that existing software is complex and difficult to use. The results obtained from existing integrated building and HVAC simulation tools also tend to be either too detailed or too simple to be of practical use to designers [6,15]. In general, these tools are perceived as being too expensive, time consuming or complex to be applied on general design problems [54].

Existing tools also do not always fit well into the current design practices. A typical example being thermal building simulation tools. These tools can greatly aid architects in designing energy efficient buildings, but they require detailed building information. To use the program, the architect must thus already have completed his design. At this stage it is too late for the thermal analysis to be effective in optimising the building thermal characteristics.

Other socio-economic reasons also influence the use of computer design tools. Program vendors do not accept any liability due to decisions made based on results obtained from their tools. Designers are therefore cautious to use methods not proven to be at least as safe and well tried as their traditional methods. According to Batty and Swann [55], some designers also see computers as a threat to their expertise and knowledge, and therefore their salary.

1.7 NEW DESIGN TOOL REQUIREMENTS

Tools that have the capability of improving the general quality of buildings are of no value if they are not applied in the design of new buildings. A workshop held on next generation building simulations tools also indicated that new tools should focus on benefiting practising designers [56]. The problems that designers' experience with existing tools consequently need to be addressed. Simplification of existing tools is probably the single most important requirement.

Complexity of design tools is born out of a growing gap in what researchers and scientists offer as design tools, and what is really used in practice [38]. Researchers and scientists are more technically orientated and require powerful and accurate models that adequately represent real world complexity. Designers on the other hand are more interested in simple, straightforward and intuitive tools.

This gap is especially evident in the user interface and language used to specify input parameters [11,13]. Models that are accurate and represent the real world complexity are more likely to require a user that has a significant understanding of the underlying modelling principals and implementation details. Designers can however be overwhelmed by the amount of information required by some of these tools. This is especially true during the initial stages of design when certain aspects are either still unknown or not yet designed.

Simplifying the data input structure and providing default design values could greatly reduce the complexity of a program. A simple input structure aids designers in providing the required data and default values can be used when the required information is not yet available or if quick estimates are required. Closely related to the simplification of input data is the time required to learn and use the program effectively.

Time is of immense value to designers. Describing and preparing data for thermal building simulation programs can take several days. Designers can however not afford to spend that much time doing this. The same holds true for calculation time and interpreting results. According to Richards [57], errors of up 20 % may be acceptable if the tool answers "what if" questions in minutes rather that hours.

An 80 % accuracy is still within design limits considering the influence that workmanship during construction, and actual utilisation of the building have on the final performance of the building. Reducing accuracy in order to save time and decrease complexity is thus a viable solution.

Language difference between scientists and designers is another barrier. An architect, not well versed in building thermal characteristics for example, will find it difficult to specify the thermodynamic properties of a building. The construction material used can however easily be defined. In doing so, some of the thermal characteristics are inherently specified.

Communication and the exchange of data between different design experts is another important aspect in optimal building design. For various practical reasons it is believed that IBD systems will not be used in the near future, but the idea of transferring data between various design applications is still worth pursuing. Where possible, the data structure of a new tool must therefore still conform to an accepted standard. These tools can then be provided with a means of importing and exporting a standard data file format.

The socio-economic aspects of design tool usage must also be taken into consideration. High on this list is the need for practical verification of all new design tools. This will ensure greater confidence in the use of design tools. Designers also need to be educated about the benefits and limitations of using these tools [55]. Marketability of design tools must also be considered. According to Stevens [24], tools that can be used to impress clients and therefore serve as a marketing tool are more likely to be used by designers.

Most of these requirements are not new. They were first identified during the third International Congress on Building Energy Management (ICBEM) in Lausanne [58]. According to Holm [59], these requirements are however too vague. Tools satisfying these requirements are not guaranteed to succeed. To be truly effective new software must also be developed in close co-operation with the designers it is intended for.

1.8 STUDY OBJECTIVES

It is believed that practical, easy to use design tools can be obtained by addressing the identified design tool requirements. Thermal efficiency of buildings and the selection of HVAC systems are two areas that can benefit from simplified tools. These aspects have a large influence on the socio-economic success of a building, but do not receive the necessary attention due the complexity and the time required for analysing the various options sufficiently.

Thermal characteristics of a building are mainly influenced by architectural design decisions made during the preliminary design stages. A need thus exists for a simplified analysis tool suited for architectural use. The first objective of this study is to develop such a design tool. This consisted mainly of:

- Simplifying input complexity by identifying and focusing on critical parameters.
- Defining input parameters in architectural terms.
- Verifying that the tool provides answers of suitable accuracy.
- Developing a simple means of comparing and rating design efficiency.
- Evaluation of design tool suitability by practising designers.

HVAC system selection ideally consists of a detailed integrated system and building performance analysis of all the systems being considered. It is however impractical and very time consuming. A simplified preliminary selection tool can aid designers in reducing the number of systems to consider to two or three. The need for detailed analysis can thus be significantly reduced. The second objective of this study is to develop such a tool.

Bloom [60] states that "communication or the lack thereof is one of the prime areas of conflict. At least four of the 15 failure factors are as a result of poor communication during the design stage". A secondary objective of the selection tool is thus to aid the designer in determining the owner's true requirements and expectations of the HVAC system performance.

1.9 CONCLUSION

Designers are increasingly pressured to design buildings with high standards of energy efficiency, performance and comfort. Computers are seen as an important modern design tool that can help lighten some of the designers' burdens. A myriad of computer applications already exists, ranging from complex finite-element applications to simple electronic nomographs. New development in this field tends to be in the areas of integrated building design and knowledge based systems.

Researchers and scientists can develop tools with the potential to greatly enhance the quality of buildings. These tools will however fail if they are not widely accepted and used by designers. Only a few building designers currently exploit the full potential of computer design tools. The general use of computers seems to be restricted to CAD and steady state calculations. This can mainly be attributed to the complexity of, and time required, for using the existing tools.

New computer design tools should address the requirements of building designers if they are to succeed in benefiting the building industry. It is important that new design tools be developed in close co-operation with building designers. In general the requirements for new design tools are:

- The tool should be simple and straightforward to use.
- It should provide default values for unknown variables. This will be especially valuable during the preliminary design stage.
- Time required to learn and use the software must be as short as possible (minutes rather than hours).
- Output should be simple yet informative.

- It should use a language familiar to designers.
- The tool must be verified and tested by designers.
- New tools should make provision for easy data transfer between different design tools.

Most of these requirements are not new. It is however clear from the literature that these items have still not been addressed to the satisfaction of designers. There is therefore still considerable scope for improvement in making design tools accessible to designers. This study addresses some of the needs by developing new simplified building and HVAC design tools for building designers.

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Chapter 2 Developing A New Simplified Thermal Design Tool For Architects

Architects form an integral link in the design of efficient buildings. Energy efficient design strategies therefore require architects and engineers to work closely together in optimising the building shell. However, this is not always practical. Architects must therefore be able to perform a preliminary thermal analysis if energy efficient design strategies are to succeed. Existing tools do not cater for this or fit their design methodology. A need therefore exists for a simplified thermal design tool for architects. This chapter discusses the development of such a tool.

2.1 INTRODUCTION

It has long been known that the building envelope has a considerable impact on thermal comfort and HVAC system size [1,2,3,4]. Hens [5] in fact states that the HVAC system and building shell are inseparable, like Siamese twins. In most cases, architects design the building shell. These designs are then passed on to HVAC engineers. They perform a thermal analysis and design the necessary systems to achieve the required comfort level [6].

According to Holm [7], the thermal analysis is done at a stage when major design decisions have already been made. It is then difficult for the architect to change his design based on the thermal analysis results. This sequential design can potentially lead to buildings that are energy inefficient and require large HVAC systems. It is therefore essential that architects can evaluate their designs before important building characteristics are frozen.

Building thermal simulation tools have a tremendous potential for aiding designers in evaluating and optimising the building envelope design. Unfortunately, existing tools do not accommodate architects nor fit into the current design process. These tools tend to be complicated and time consuming to use. Furthermore, they often require detailed information of the building construction. Existing tools have thus so far failed to be incorporated into the general design practice [8]. A need for a simplified thermal design tool for architects therefore still exists.

A new thermal design tool was developed to fulfil the above requirements by addressing the needs identified by the design community in Lausanne [9]. The tool was simplified by reducing the number of input parameters and defining them in terms that architects can relate to. The output of the program further enables designers to quickly evaluate their design without the need for detailed processing of the analysis results. These properties make the design tool ideal for use early in the design.

2.2 INTEGRATED BUILDING AND HVAC DESIGN

Buildings serve a dual function. They provide a comfortable working and living environment that protects the occupants from harsh climatic conditions, and they serve as an expression of the owners' style, status and individualism. Buildings must therefore be aesthetically pleasing yet functional. Before the advent of electricity and mechanical HVAC equipment this was achieved by incorporating passive comfort design features into the building structure [6,10].

The once integrated design process evolved into a sequential process with the development of fluorescent lights and mechanical HVAC equipment [6]. This equipment made it possible to obtain indoor comfort anywhere in a building. Freed from the comfort constraints, architects could design buildings based purely on aesthetics. These designs were then passed on to HVAC designers. They devised the necessary systems needed to achieve comfort. Close co-operation between the various design disciplines consequently ceased to exist.

Lack of communication and close co-operation between the various design disciplines is seen as one of the major causes of energy inefficient and uncomfortable buildings [11,12,13,14]. Blaine [13] believes that poor design integration is mostly responsible for buildings diagnosed with Sick Building Syndrome (SBS). Some building owners and developers are thus requiring architects and engineers to work closely together [15]. Regaining the lost art of integrated building and HVAC design is therefore receiving a lot of attention [1,6,12,16].

2.3 IMPORTANCE OF INITIAL DESIGN STAGES

Building designers typically follow a top-down design procedure when designing new buildings [7,17,18]. It consists of initially starting with the building as a whole and then working down to smaller detail, such as colour and wall finishes. This process is divided into several design stages [19,20]. The definition and detail of the various design stages may vary for different designers, but the basic idea remains the same.

Typical stages of building design are as follows:

- *Design briefing stage*- the initial specifications of the building are fixed with respect to function and size;
- *Preliminary design stage*- during this stage the building orientation, general construction, and window areas are defined and set;
- *Detailed design stage* - final decisions on building interior layout, construction and colour are made;
- *Construction documentation stage* - specifications and detailed working drawings are drawn up. This documentation is put out for tender;
- *Contract administration stage* - a contractor is selected and the building is constructed. During this stage the architect oversees the works and performs general administration.

The initial design stages form the foundation of all new building designs. During these stages the general size, orientation and construction of the building are defined. All subsequent decisions and design calculations are based on these characteristics. It therefore becomes more difficult and costly to alter the design as it progresses. Decisions made early on, without careful consideration or knowledge of their consequences can have a dire effect. It is therefore essential that thermal analysis and feedback start early in the design process.

This top-down design practice has evolved over a long period of time. It is therefore unlikely that this approach will change radically in the foreseeable future. Energy efficient design strategies need to take this into consideration. If a strategy alters the design process too much, it will most likely not be used extensively [21].

2.4 THE ARCHITECT AND THERMAL DESIGN

The Integrated Design Approach (IDA) is suggested as a simple inexpensive means of achieving energy efficient and comfortable buildings [16]. Figure 2.1 shows a simple flow chart of this approach. Minimising the building load is the first step in designing new energy efficient buildings. This load is mainly affected by the building shape, form and thermal characteristics [3,4]. Architects consequently have a significant effect on the building load.

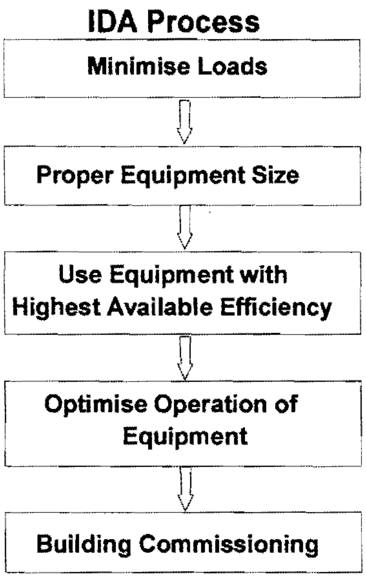

Figure 2.1 – Integrated building design approach [16]

Building thermal efficiency is only one of many items to be considered by the architect. According to Holm [7], it is often given little or no thought at all during the design of the building. He further states that this can be attributed to the fact that many architects and building owners have not been exposed to the realities of life-cycle energy cost, nor its social and environmental impact. Initial cost of the building and its aesthetic value are therefore frequently still used as basis for evaluating the design.

Thermal design requires the architect to allocate more of his time and resources to considering the thermal impact of his design decisions. Holm [7] states that "the architect doing thermal design does so at considerable additional cost to himself, putting himself at risk while the building owner enjoys the long-term benefit, often without paying for it." There is thus little incentive for architects to perform thermal load analyses.

Currently, HVAC designers usually perform building thermal load analyses in order to determine the size of the HVAC system. It is thus only done after most of the building design has been finalised. The critical initial design stages have thus already been completed making it difficult and expensive to change the design based on its results.

Building thermal characteristics must be analysed and modified if needed before significant design decisions are fixed. This can typically help to avoid buildings with large glazing areas, without due consideration to solar heat gains. If the IDA is to succeed, it is essential that architects become involved in minimising the building load when designing the building shell.

2.5 THE NEED FOR A THERMAL DESIGN TOOL FOR ARCHITECTS

Most new energy efficient design strategies require the architect and HVAC engineer to work closely together in minimising the building load. Ideally, these two design professionals need to be appointed at the same time. This however does not always fit into current design practice. In many cases, the building design is near completion when the HVAC engineer is first appointed [11]. The critical, initial design stages have by then already been completed. Architects must therefore be able to perform some preliminary thermal analyses on their own.

Building simulation is seen as an ideal tool to aid designers with thermal analysis [1]. Using a simulation tool it is possible to determine the effect various design decisions will have on the building load. Changes can thus be made before major design decisions are fixed. There are a host of simulation tools available for use by designers. To date these tools have however largely failed to be applied into the building design process.

Various speakers discussed this lack of use during the 1997 International Building Performance Simulation Association (IBPSA) conference held in Prague. Complexity and the time required to use these tools are frequently cited as reasons for this. The users further require knowledge of thermal and numerical analysis [22]. Architects, in general, are not well versed in these areas.

Detail required to generate a thermal model of the building is also a major limitation. Most of the information needed for simulation is not yet available during the preliminary design stages when analysis is most needed [7,23]. According to Holm [7], the thermal simulation process is diametrically in the opposite direction of the architectural design approach.

Another trend in new software development is towards total building energy estimation. These tools therefore incorporate elementary lighting and HVAC system simulation. Although beneficial during subsequent design stages, these features tend to cloud the impact of architectural design decisions by a host of other data. Existing simulation tools consequently do not cater for architects or aid them in designing the building thermal shell. These obstacles must be addressed if architects are to be encouraged to perform preliminary thermal analysis. There consequently exists a need for a simplified thermal design tool for architects.

2.6 DESIGN TOOL REQUIREMENTS FOR ARCHITECTS

The first step in developing a new thermal design tool for architects is to determine their requirements. The basic needs identified during the third International Congress on Building Management (ICBEM) in Lausanne [9] are still applicable today. They are as follows (adapted from Holm [7]):

1. The design tool should be user friendly and easy to use.
2. Input formats must be user orientated and in terms of building materials rather than thermal properties.
3. Solutions must be obtained quickly, in minutes rather than hours. This is more important than the accuracy of the tool.
4. It should be able to handle 'what if' alternatives readily.

The social component of design tools is another often-overlooked factor [24]. The fears and reservations that designers have in the use of these tools should also be addressed. It is consequently important that designers are aware of the merits and limitations of using the design tool [14]. The tool must thus be extensively verified. A tool that can be used for marketing or has financial benefits is furthermore also more likely to succeed according to

Stevens [24]. This will give architects an incentive for using the tool. These requirements must be reflected in the input, simulation and output of the new design tool.

2.7 SIMPLIFYING THE INPUT REQUIREMENTS

The user interface and data required by the tool forms an important link between the designer and the design tool. Tools that overwhelm architects with the amount of input data or knowledge required will not be used. This is especially true in countries where architects are not legally bound to perform building thermal analyses. One of the main areas of development is consequently in making existing tools accessible to designers.

Improvements in computing power and graphic capabilities have resulted in more "user-friendly" interfaces than the old ASCII based text files. A survey conducted on users of thermal simulation programs however still indicate that this area requires attention [25]. Complexity of the input structure is believed to be one of the main contributing factors.

Irving [26] states that "the probability of pure user-injected mistakes usually increases with the complexity of the input structure. Much of this complexity arises from geometrical specification of the building and in level of the building detail described." Transferring data from building drawings directly into the simulation program has been suggested as a solution to this problem. Geometrical and construction information is stored in computer generated architectural drawings. The simulation tool accesses the drawing database for the necessary information.

Connecting CAD[1] software with building simulation programs seems to be a clever solution. It is however not suitable for preliminary architectural design. During this stage, the building is defined in a very coarse manner. The requirements of the building developer are normally expressed as sentences, rather than sketches. These tools will thus require the architect to complete his design before performing the thermal analysis. Morel [21] lists various other drawbacks and problems that this approach has.

[1] Computer-aided drafting

The use of default values and automatic generation of complex building models is an alternative means of simplifying the use of simulation tools. Default values can greatly aid designers in obtaining useable design values for parameters that are still unknown. However, they do not necessarily reduce the input structure complexity. To solve this problem, the number of input parameters must be restricted to a minimum.

A Danish study indicates that by using as few as six user-specified parameters, it is possible to auto-generate complex building models with reasonable accuracy [27]. This tool is based on statistical information of existing buildings to determine their construction. The Finnish WINETANA program follows a similar approach [28]. These applications are restricted to the building types used to generate the statistical knowledge database. It is however believed that a similar reduction in input parameters can be obtained using Pareto's law of distribution.

Vilfredo Pareto (1848-1923), an Italian economist and engineer developed a curve known as Pareto's law of distribution. This curve has a general application in areas where a significant number of elements are involved. It indicates that 20% of the elements are generally responsible for 80% of their total effect [29]. In building design terms, twenty percent of the design parameters are largely responsible for the building thermal performance.

A logical deduction is that this also applies to the input data required by building simulation tools. A good indication of a building's performance can thus be obtained by specifying a few critical elements and defining the remaining from typical values for the specific building type. The added advantage of this is that architects need only consider and analyse design parameters that have a huge effect on thermal efficiency.

2.8 CRITICAL INPUT PARAMETERS

There are two elements that need to be considered when establishing the critical input parameters for the architectural design tool. The first consists of determining whether the parameter has a significant effect on the thermal response of the building. The second involves focusing on parameters that are directly influenced by architectural design decisions.

During the preliminary design stages, architectural design decisions consist mainly of defining the building size, form, glazing and general construction. Identifying the important parameters however, is not that simple, since they influence each other. A study done by Shaviv [30] on typical Israeli residential buildings however revealed that design parameters can be divided into three categories.

The first category consists of parameters with a weak effect on the building thermal performance, and thus insensitive to other design parameters. Parameters that have a strong influence but are not affected by other design parameters form the second category. The third category consists of parameters that have a strong effect on building performance and also sensitive to other parameters.

Using the above categories as basis it is possible to reduce the input requirements for the architectural design tool. Parameters of the first and second category, such as internal loads, ventilation, temperature setpoints and operating hours can be modified during the final design stage without compromising other design features. They thus require little attention and can be specified using default values. The third group forms the critical input parameters for thermal simulation.

In order to establish the critical input parameters for the design tool, a sensitivity analysis was performed. It consisted of changing the design parameter of interest and noting the effect that the change has on the building load. This is repeating for various building configurations and climatic conditions in order to obtain a sufficient set of data from which the typical influence of the parameter on building load can be obtained.

The average value of the data indicates the mean influence that the parameter has on the building load. The standard deviation of the data from the mean value shows how much the parameter is influenced by other design criteria. Critical parameters would on average cause a large change in the building load relative to a small change in the design parameter. This relationship is referred to as the sensitivity ratio.

Except for construction material, the sensitivity ratio of the analysed parameters was calculated as the percentage change in load divided by the percentage change in the design parameter. Construction material choice affects thermal mass and conductivity. It is thus difficult to express it in terms of a change in one parameter. Its ratio is consequently defined as the percentage change in load due to a change in material.

By defining the ratios in the above manner it is possible to compare parameters with small value changes, such as the number of zones, with parameters with large numerical changes such as the window area. Table 2.1 indicates the sensitivity analysis results for over 2000 base building configurations. The results indicate a strong sensitivity towards window area, roof colour and internal loads.

A small change in the above parameters would have a large influence on the building load. A substantial reduction in the load can thus be obtained by changing these parameters. There is also a huge difference in choosing building materials with a high thermal mass and high conductivity, compared to a heavy construction with low thermal conductivity. Using these results as basis it is possible to simplify the architectural design tool input requirements.

Parameter	Summer		Winter	
	Avg. sensitivity ratio	Std. Deviation	Avg. sensitivity ratio	Std. Deviation
Number of zones	5.1	4.5	10.1	7.5
Window area	42	34	34	23
Wall ratios	1.3	1.5	1.2	1.5
Shading – Windows	7.8	9.7	3.5	3.1
Shading – Walls	2.1	1.7	1.2	0.3
Wall colour	3	2.5	1.3	0.5
Roof colour	84.7	7.3	9.0	2.0
Internal loads	60.5	8.7	59.7	7.8
Construction material	83.1	-	60.5	-

Table 2.1 – The influence of various design criteria on the building load

2.9 PROGRAM INPUT

One of the main input requirements of thermal analysis tools is the geometric specification of the building. It is believed that most buildings can be approximated as a square or as the sum of multiple squares. The equivalent projected areas can be used to approximate buildings that are not exactly rectangular. It is hence only necessary to specify floor area, building height and the length of one wall to sufficiently describe the building geometry for the purpose of a preliminary thermal analysis.

The above simplification is possible as the sensitivity analysis showed that the number of zones and the wall ratio's, i.e. North/South wall length relative East/West wall length has small effect on the total building thermal load. In practice these items however influence the load diversity of the required air-conditioning system and must be taken into consideration during later design stages. For the purposes of the design tool the North/South wall length is used as input since this façade is usually exposed to the most solar radiation.

Window area and its orientation are other input parameters required by the design tool. During the preliminary stages of design, the exact window size and their position has not yet been determined. Window area is thus rather specified as a percentage of the wall area, making it easier for the architect to estimate. Generally the window type will not vary and therefore only needs to be specified once.

Shading on the windows and walls further effects the total building load. However, calculating the shaded area is a complex process. It requires the dimensions and positions of the shading devices. These dimensions are only finalised later in the design process. Fortunately the analysis indicates that these items can be simplified. The design tool takes shading on windows into consideration by requiring the user to specify the percentage of shaded window area. The influence of shading on the walls is assumed to be insignificant and thus disregarded.

The colour of exterior surfaces influences the short-wave absorptance characteristics of the building. Darker coloured materials absorb more solar radiation than lighter coloured material. Wall colour has a small effect, as it generally does not receive all the solar radiation. The roof on the other hand is directly exposed to solar radiation and is therefore more sensitive towards colour.

The effect of colour is taken into consideration by allowing the architect to indicate if the walls and roof are light, medium or dark coloured. Solar absorptance characteristics of the exterior surfaces are then adjusted accordingly. The effect of roof colour reduces for high-rise buildings. This ties in with the fact that energy efficient buildings enclose the largest volume for the least surface area [6].

The thermal mass and overall heat transfer coefficient of the surface area plays a major role in defining the thermal characteristics of the building. These items depend on the materials used to construct the building. There is theoretically an infinite number of potential combinations. In practice it can however be restricted to a few representative construction types. ASHRAE [31] and CIBSE [32] provide typical American and British construction types.

A similar set was identified for South Africa and is provided in Appendix A. Construction of the building can be defined by simply selecting the wall, roof and floor assembly that closely matches the qualities of the proposed construction. This process can further be simplified by providing architects with a graphic interface for selecting the appropriate assembly. Figure 2.2 provides an example of such a graphic interface for selecting wall construction.

Internal heat generation is generally a parameter of the second category. It can however influence decisions regarding the building construction. Insulated buildings with high internal loads can cause unwanted heat to become trapped inside the building. In such cases it may be more beneficial to use building material with a higher conductance. This is taken into consideration by allowing the architect to either use a typical Watt per square meter default value or specify the load if it is known.

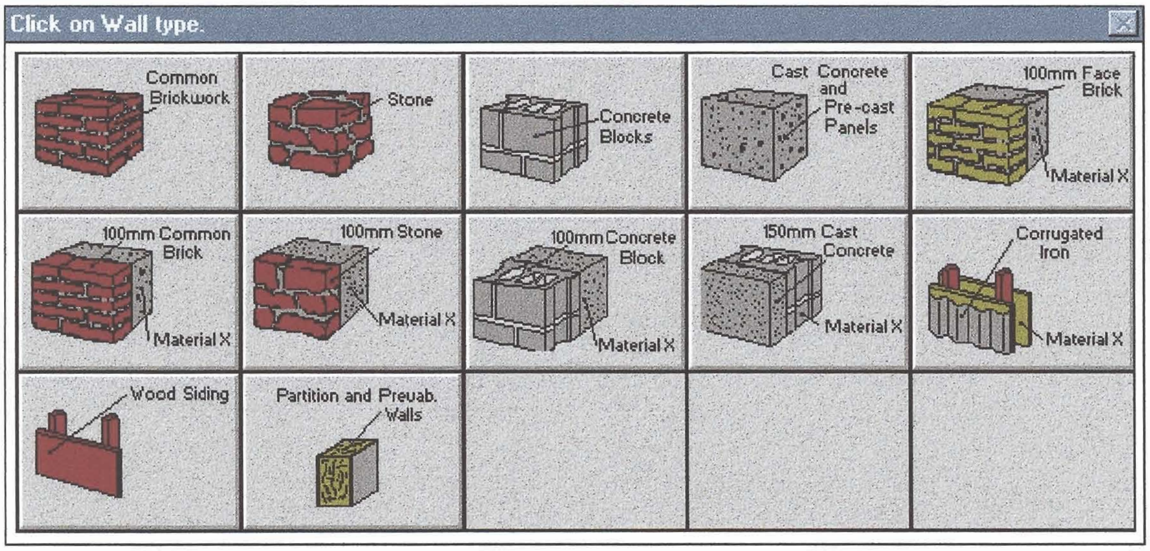

Figure 2.2 – Typical graphic interface for selecting building construction assemblies.

Other input parameters required for thermal simulations are the climate, building type, and orientation. The building type is required for determining default values such as load and ventilation. Climate is selected according to the climatic region in which the building is located. This is facilitated using a graphic interface consisting of a map indicating the regions. Building orientation is a reference angle relative to North with which the designer can specify the orientation of the building in cases were the walls do not face North/South or East/West.

The results of the above research findings made it possible to considerably reduce the input complexity required by thermal simulation tools. A validation study was performed using measured data to further ensure that all the critical design parameters are taken into consideration. The results of this validation study are presented in Chapter 3.

A new simplified design tool for architects was developed and commercialised in conjunction with TEMMI/MCI[2] using the above as basis. Figure 2.3 indicates the user-input interface of the tool. Graphic interfaces for choosing climate, orientation and building construction are all activated from this screen. From the input information the geometry of the building is defined automatically and thermal characteristics of the building material set. Default values are set according to the chosen building type as indicated in Appendix A.

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[2] TEMMI/MCI (Pty) Ltd. P.O. Box 13516 Hatfield 0028, South Africa

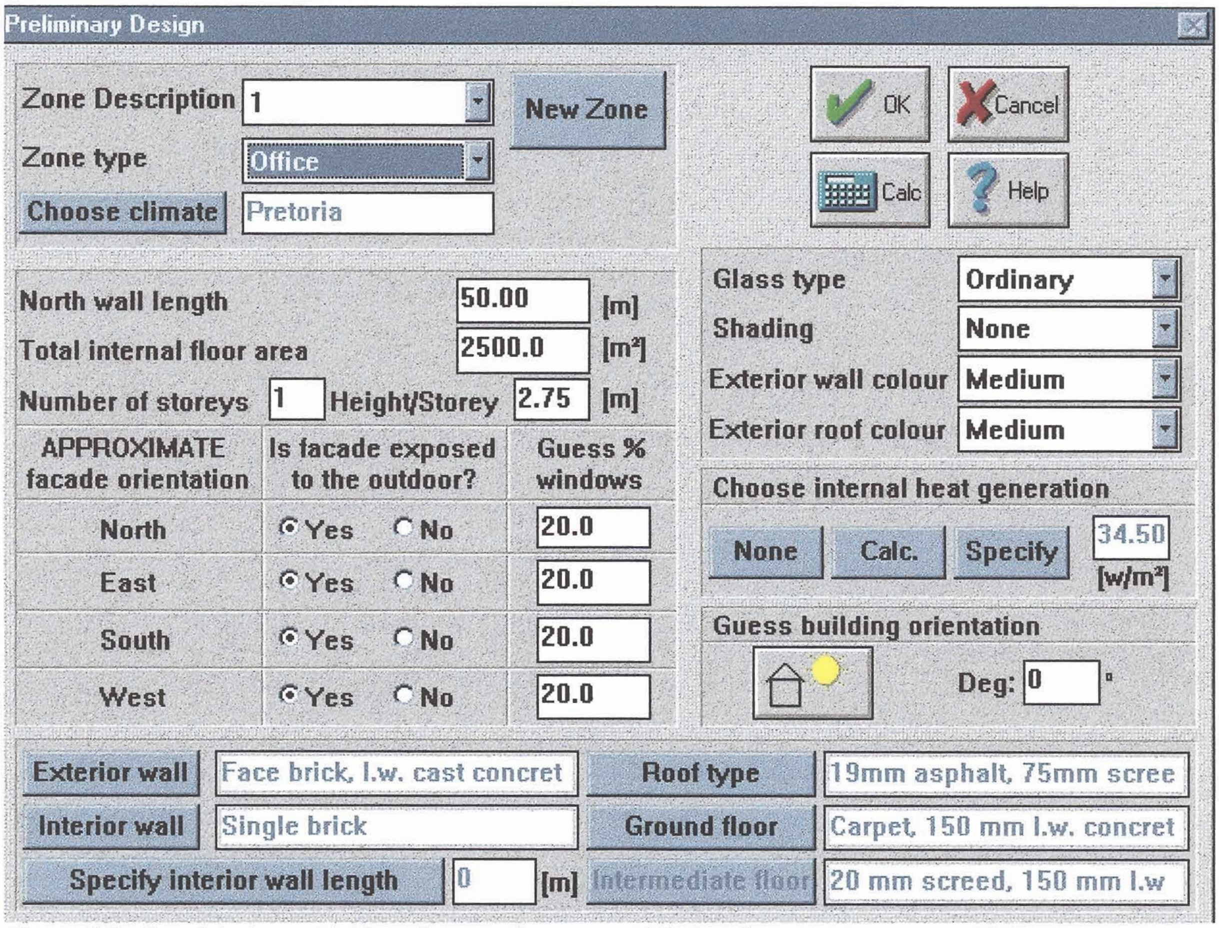

Figure 2.3 - Simplified user interface for specifying critical design data

2.10 SIMULATION MODEL

The simplified design tool uses the simulation model developed by Van Heerden and Mathews [33,34]. It consists of a triple node electrical analogy for solving the building thermal network. This model has been extensively verified and used in practice. The model therefore has an established track record and credibility. These are important factors if the new tool is to be accepted by the design community.

Simulation time is approximately 5 seconds using a PII-266 personal computer. The simulation consists of performing a hot and cold day simulation for a single zone. The model can be used to calculate both HVAC loads and as a passive design tool for estimating indoor temperatures. It has been applied in a more detailed integrated building and HVAC simulation tool, namely QUICKcontrol [35].

An additional benefit of using this model is that the preliminary design data can easily be transferred to the detailed simulation tool. The preliminary design information only needs to be slightly modified for use during the detail design stage. This typically consists of changing the default design characteristics, such as ventilation, occupancy or internal load profiles so that it reflects the actual design conditions. It consequently saves the engineer time and enhances communication between the architect and HVAC engineer.

2.11 OUTPUT CONSIDERATIONS

The output of existing design tools is another area that needs attention. Output from sophisticated tools tend to be too detailed, making it difficult for the architect to interpret [11,28]. These tools typically provide a breakdown of monthly energy loads, utility bill predictions, peak load analyses, demand charge evaluations, etc. of the building, HVAC system and lighting combination. The effect that architectural design decisions have on the building shell performance is thus diminished by other data.

Graphic representation of the results allows the user to quickly get a qualitative evaluation of the building. Post processing of data is however still required for comparing the performance of different designs. Furthermore, such a detailed output is impractical for a simplified design tool due to the numerous assumptions and simplifications made. A comparative analysis between design alternatives subjected to the same assumptions will be more credible.

In order to handle 'what if' alternatives readily, the tool must have an automatic means of comparing and ranking the various design alternatives. Energy-10 [36], distributed by the PSIC council, is a good example of a tool that applies such a ranking scheme. It ranks various energy savings schemes such as energy efficient lighting and the use of optimised HVAC controls against each other. The ranking is based on estimated building energy consumption.

A similar rating scheme for comparing the thermal efficiency of building shells can be obtained using the building load as basis. The design is given a rating out of five depending on how it compares to a reference building of minimum acceptable thermal efficiency. The smaller the load, the higher the rating and thus the more thermally efficient the design. Using this method architect's can quickly assess whether their design satisfies building regulations.

Improvements in design alternatives are also expressed in terms of a percentage reduction in heating and cooling load. This is necessary to reflect small changes that do not effect the design ranking. Comparison between design alternatives can thus also easily and quickly be accomplished.

An added advantage of such a rating scheme is that design firms can use it as a means of marketing themselves [37]. The downside of the rating scheme is that it is dependent on climate and building type. It was consequently necessary that such a rating scheme be developed for the tool. In chapter 4 the rating scheme for South African residential and office are developed in detail.

2.12 FEEDBACK FROM DESIGNERS

The new simplified design tool addresses all the static requirements identified in a previous section. A tool that fulfils these requirements is however not necessarily guaranteed to succeed. Holm [7] states that design tool development must be done in close co-operation with the people it is intended for. The reason being that it is impossible to determine in advance exactly what design professionals need and expect from design tools. The new tool was consequently developed in close co-operation with design professionals.

During the initial development, architects were asked to use the program. They were observed to identify problem areas and see how they interact with the program. The user interface was then modified based on these observations. The final product was re-evaluated by providing it to a group of 26 consisting of practising engineers and architects. They were required to complete a questioner on the use of the design tool.

All 26 indicated that they find the tool useful and easy to use. Twenty-three of the twenty-six indicated that they would use the program of which twenty further stated that the program would aid them in improving their designs. Feedback from these designers was thus very positive. It is thus believed that the tool successfully addresses the need of the design community.

2.13 POTENTIAL IMPACT AND IMPLEMENTATION

Researchers believe that energy savings of around 30% can be obtained by using improved design and management practices, and through retrofit projects of existing commercial buildings [38]. A study performed by Todesco indicates that on an individual level, architectural optimisation can result in energy savings of roughly 10% [6]. These savings however also affect the initial capital cost of the HVAC system and the environment.

A smaller and thus cheaper HVAC system will be required for buildings with an optimised thermal shell. In some cases, the use of air-conditioning systems can be avoided completely. Environmental benefits are a decreased depletion rate of non-renewable energy sources and a reduction in atmospheric pollution. Using the new tool, these savings can potentially be obtained by spending between 30 to 60 minutes more on the design of the building shell.

It is believed that architects will be hesitant to purchase and apply the new thermal design tool before it has been proven to be beneficial to them. One of the more difficult tasks is thus to initially get architects interested in using the new tool. It is suggested that manufacturers of insulation and glazing material as well as electrical utility companies sponsor the development and distribution of the tool.

The manufacturers would provide the tool to their customers as a means of marketing their products. Architects will then be able to see what the advantages of using the manufacturer's insulation and special glazing types are. As architects become more familiar with the tool, they will also start to experiment with the other design parameters. In the long run this will save energy, thus benefiting the client, the utility company and the environment.

2.14 CONCLUSION

The thermal characteristics of a building are largely influenced by design decisions made by the architect during the preliminary design phase. They consequently have a major role to play in the design of energy efficient and comfortable buildings. Unfortunately, architects hardly ever consider the building thermal efficiency at this stage of the design process. Often, thermal analysis of the building is only done after most of the design has been completed. At this stage it is too late to make changes based on the analysis results.

To be effective, thermal analysis must be performed during the preliminary design stages, before critical decisions are fixed. Existing thermal design tools do not cater for architects or fit their design methodology. A new simplified thermal design tool was developed to address these problems. Innovative features of the new tool are that the input complexity is reduced considerably without having to simplify the thermal building model, and a new ranking evaluation method that enables an architect to quickly compare different design variations.

The tool enables architects to reduce building energy consumption, save on the initial HVAC system cost, and benefit the environment by spending as little as 30 to 60 minutes more on the design of the building shell. An additional advantage of the new tool is that it uses the same simulation model as an existing integrated building and HVAC design tool. Project data is easily transferred from the preliminary design stage to the detailed design stage. The tool thus improves communication between the architect and engineer.

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Chapter 3 Verification And Testing Of New Simplified Thermal Design Tool

Extensive testing and validation of design tools is of paramount importance. It provides valuable information regarding the accuracy and capability of the tool. It further serves to increase the confidence and credibility in the use of the tool. Professional designers are unlikely to accept or widely employ tools that they are not confident in. An empirical validation study was consequently performed on the new simplified building thermal design tool. This chapter presents the results of this study.

NOMENCLATURE

ach : Air changes per hour

T : Absolute temperature, K

V : Velocity, m/s

Subscripts

i : Inside

o : Outside

3.1 INTRODUCTION

Validation and testing should form an integral part in the development of new design tools. It ensures that the underlying models and assumptions are error free and valid [1]. It further serves to substantiate that the tool produces satisfactorily accurate answers within its scope of application [2]. This is especially important for establishing confidence and credibility in the use of the tool. These are essential characteristics if the tool is to be applied to real-world design problems.

An empirical validation study was performed to ascertain the validity of the new thermal design tool. This required that the tool yield results that are within an acceptable accuracy range for a convincing number of case studies. One hundred and three verification studies from fifty-six different building zones were performed for this purpose.

3.2 VERIFICATION AND VALIDATION OF DESIGN TOOLS

Verification and validation of building analysis tools is generally neglected or only performed as an afterthought [1,3]. Lack of a well-defined methodology and difficulties in obtaining good data sets are often stated as the reasons for this [4]. Shortage of funds, time and published information also contributes to this problem [5]. Verification is however essential, especially since critical assumptions are made during the development of these tools. Some of these assumptions can only be proved valid by extensive verification.

Validation of design tools can be attempted by using either one or more of the following three techniques [3]:

- *analytical verification,* in which the model is tested and compared to exact solutions;
- *inter-model comparisons*, where predictions of different tools are compared;
- *empirical validation,* where the tool's predictions are compared to measurements taken on real buildings.

Irving [3] and Bowman et al [6] describe the advantages and disadvantages of these methods. Of these, empirical validation has the greatest potential. It provides a good indication of the validity of the tool compared to the physical reality. It is unfortunately also fraught with difficulties and uncertainties [6].

3.3 VERIFICATION OF THE NEW THERMAL DESIGN TOOL

The new design tool developed during this study uses a six node electrical analogue model developed by Van Heerden [7,8]. This model has been extensively tested. The input requirements for the new design tool have however been significantly simplified since it is to be used as a preliminary design tool. The data used by Van Heerden was consequently used again to test the validity of the simplified design tool.

Two tests were performed. The first analysis consisted of testing the simplified building shell in combination with the use of default load and ventilation profiles. During this test the internal load (a Watt per square metre value) was applied from 08h00 to 17h00. This load was taken to be 40 % convective and 60 % radiative. The same model used by Richards [1] and Van Heerden [7] was used to calculate infiltration, where

$$\text{ach} = 1.5(0.215 + .042V + .013|T_o - T_i|) \quad . \qquad (3.1)$$

No natural or mechanical ventilation was included in this study.

Indoor loads and ventilation do however have a direct influence on the indoor temperature node [9]. To isolate the effect of the simplified building shell a second validation study was performed. For this study the indoor loads, infiltration and ventilation were taken to be the same as used measured.

Both studies were performed using the actual measured weather data instead of the default design data. This was necessary since measurements were not taken under design day conditions. This does not compromise the validity of the study. It can be assumed that if the tool is valid for a range of different climatic data, it will also be valid for the design weather data.

The thermal properties of the building materials used in the analyses are presented in Appendix A. These properties, as used by Van Heerden, were obtained from tables available in the literature [10,11], and were thus not measured. Measuring these properties could have eliminated some of the inherent uncertainties of this validation study. This information is however usually available to designers and consequently used by them. These are also the default values used by the new thermal design tool.

Although most of the building zones formed part of multi-zoned buildings, only fourteen studies are listed as multi-zone experiments. The indoor air temperatures in these fourteen zones differed considerably from the air temperatures in adjacent zones. In all other cases, the assumption of similar temperatures in the zone under consideration and adjacent zones was acceptable. This is one of the primary assumptions used for the design tool.

These multi-zoned buildings fall out of the scope of the simplified design tool, and were therefore not included in the global evaluation of the tool. They are however included for completeness of this study and to determine the extent of this limitation.

3.4 DESCRIPTION OF THE 56 BUILDING ZONES

Validation studies were performed using 56 different building zones obtained from various types of buildings. To extend the study, some of these zones were modified by adding insulation, changing exterior colours, opening and closing windows, generating heat, and so forth. This section only describes the basic building zones, while the following section describes the modifications made to arrive at a total of 103 case studies.

Experim 1 ***(Study 1, -5, -9, -13, -17, -21, -25)*****, Experim 2** ***(Study 2, -6, -10, -14, -18, -22)*****, Experim 3** ***(Study 3, -7, -11, -15, -19)*****, and Experim 4** ***(Study 4, -8, -12, -16, -20, -23, -24)*****:** These single-zone experimental huts are all situated in close proximity and it can be assumed that they are subjected to approximately the same outdoor environment. The buildings are surrounded by a few other low-rise buildings on a fairly open test terrain of the National Building Research Institute in Pretoria. The construction of the huts is nearly identical except for the roofs. The first two huts have identical corrugated iron roofs, the third hut has a tiled roof, and the fourth hut has a high-mass concrete slab as a roof. Various studies were conducted in the buildings by modifying the construction, exterior colour and window operation. The buildings were not furnished.

Bedroom 1 ***(study26 to study31)*****:** This furnished room forms part of a townhouse in a residential area in Centurion. The adjacent rooms are a study and a dining room. The door leading into the rest of the building was left open while measurements were taken. The room was not occupied.

Bedroom 2 ***(study32)*****:** This furnished room forms part of a house in a residential area in Wingate Park, Pretoria. The adjacent rooms are a living area and another bedroom. The exposed facade is shaded by a big tree. The door was closed and the room was unoccupied during the validation study.

Bedroom 3 ***(study33)*****:** This furnished room is situated on the first floor of a house in a residential area in Moreleta Park, Pretoria. The adjacent rooms are two bathrooms. The door was closed and the room was unoccupied during the validation study.

Bathroom ***(study34)*****:** This room forms part of a house in a residential area in Faerie Glen, Pretoria. The adjacent rooms are a bedroom and living area. The door was closed and the room was unoccupied during the validation study. Plants cover the exposed southern wall. Large mirrors are attached to some indoor surfaces.

Dormit 1 ***(study35 to study37)*** **and Dormit 2** ***(study38 to study40)*****:** These pre-cast concrete units form part of an arrangement consisting of twenty units. The buildings are situated in the Negev desert in Israel. Indoor partition walls divide the units into four smaller zones. Indoor temperature measurements are however representative of the whole unit. The large windows are fitted with externally adjustable PVC louvers acting as a shading device. During monitoring the units were unoccupied.

Prefab ***(study41 to study43)*****:** This low-mass prefabricated unit is situated in an open area in the Negev desert in Israel. The building consists of two similar zones, separated by a dividing wall without a door. Only one of the zones was monitored. During monitoring the units were unoccupied. The building is placed on steel beams approximately 20 cm above the ground. Windows are fitted with external shading devices consisting of adjustable PVC louvers.

Garage ***(study44 and study45)*****:** This empty garage is attached to a townhouse similar to the description given for Bedroom 1. No ceiling is provided and the southern wall consists mainly of a steel door.

Shop ***(study46 to study48)*****:** The vacant shop is located in a single storied shopping mall in the low-rise city centre of Centurion. Exposed glazing is well protected by building eaves. The interior walls are shared by an adjoining restaurant and a loading zone.

School 1 ***(study49 and study50)*****:** The monitored classroom is on the third floor of a school situated in a residential area in Menlo Park, Pretoria. The adjacent rooms are another classroom and a storeroom. Measurements were taken during the holidays and the rooms were therefore not occupied. The room is furnished with school desks and chairs.

School 2 ***(study51)*****:** The walls of this single-storied classroom are made from prefabricated asbestos cement panels. An adjacent classroom was occupied during validation but the room under consideration was used to store various pieces of furniture. The school is situated in a residential area in The Willows, Pretoria.

Store 1 ***(study52)*****:** The storeroom is attached to another storeroom and a classroom at the same school described as School 2. Clothing was stored on shelves against the walls and on parts of the floor.

Store 2 ***(study53)*****:** This single-zone corrugated iron store is situated on an open area in the industrial area of the rural town of Volksrust. The store was vacant and closed during the validation study. Ventilation was achieved by means of ventilation openings in the roof.

Studio ***(study54)*****:** The southern and western external walls of this studio consist of very large glazing areas allowing solar penetration. Walls are fairly high and a ventilation opening is located in the roof. Interior partition walls form a smaller zone inside the main building. The studio is used as a showroom for furniture and is situated in a residential area in Brooklyn, Pretoria. Validation was done on a Sunday when the building was closed.

Church ***(study55)*****:** The church was designed with the aim to achieve sound human comfort and hence incorporates various techniques enhancing natural ventilation. The main zone of the church can be considered as a single zone with fairly high walls. It is situated in a residential area in Arcadia, Pretoria, and is surrounded by various high trees. Monitoring was done on a Sunday and consequently includes church services in the morning and in the evening.

Factory ***(study56)*****:** The building is situated on an exposed terrain in Groenkloof, Pretoria, with no surrounding buildings. It is naturally ventilated by means of roll doors at ground level and roof-mounted ventilators. The factory was used for the assembly of mechanical components with no significant heat generation during monitoring. At least half of the roll doors were kept open during the day. The south wall is a partition between the zone under consideration and another factory.

Office 1 ***(study57 and study58)*****:** This office is on the second floor of a naturally ventilated office block on the grounds of the Council for Scientific and Industrial Research in Pretoria. The building is situated on an open terrain but is sheltered by other buildings. High-mass beams are located in the roof. The office was vacant during monitoring.

Office 2 ***(study59)*****, Office 3** ***(study60 and study61)*** **and Office 4** ***(study62)*****:** These three adjacent offices are on the first floor of the air-conditioned G H Marais building in the city centre of Pretoria. Office 2 faces east, Office 3 is on the corner of the building facing north-east, and Office 4 faces north. The floors of Office 2 and Office 4 are exposed to an open parking area, while Office 3 is above the air-conditioning plant room. The offices were furnished but vacant, and closed during monitoring. The air-conditioning was also inoperative for validation purposes.

Office 5 ***(study63)*****:** This office is in the naturally ventilated Central Governments Office building in the city centre of Pretoria. The office was occupied during the day.

Office 6 ***(study64)*****:** This office is on the 22nd and top floor of the Liberty Life building in the city centre of Pretoria. The office was occupied during the day but air-conditioning equipment was inoperative.

Office 7 ***(study65)*****:** This office is on the 16th floor of the Poyntons building in the city centre of Pretoria. The office was furnished but vacant and closed during monitoring. Air-conditioning equipment was inoperative.

Office 8 ***(study66)*****:** This office is on the fourth floor of the UNISA building near the city centre of Pretoria. The office was furnished but vacant and closed during monitoring. Air-conditioning equipment was in operation.

Office 9 ***(study67)*** **and Office 10** ***(study68)*****:** These offices are on the 9th floor of the air-conditioned Engineering Tower Block on the campus of the University of Pretoria. The offices were furnished but vacant and closed during monitoring. Air-conditioning equipment was inoperative.

Office 11 ***(study69)*** **and Office 12** ***(study70)*****:** These offices are on the second floor of the J G Strijdom building on the campus of the University of Pretoria. Office 11 was empty and Office 12 was furnished but vacant and closed during monitoring. Air-conditioning equipment was inoperative.

Lightweight ***(study71 and study73)*** **and Heavyweight** ***(study72 and study 74)*****:** These are two buildings at the Desert Architecture Unit of the Jacob Blaustein Institute for Desert Architecture at the Ben Gurion University in Israel. The lightweight building is a prefabricated building. The heavyweight building is a demonstration building of heavy construction.

The next 23 studies were conducted at animal laboratories on the Onderstepoort campus of the University of Pretoria. Three separate facilities on the campus were included in the case studies namely, the conventional laboratory-animal facility, the infectious-diseases facility and the metabolic facility.

Room 1-79 ***(study79)*****, Room 1-80** ***(study80)*****, Room 1-82** ***(study81)*****, Room 1-83** ***(study82)*****, Room 1-90** ***(study76)*****, Room 1-91** ***(study75)*****, Room 1-93** ***(study78)*****, Room 1-94** ***(study77)*****:** These rooms housed cats, dogs and rodents and were supplied with two constant volume direct expansion units. The supply airflow rate and temperature were measured and entered as the ventilation data for these rooms.

Room 1-122 and 1-123, Room 1-125 to 1-127, Room 1-141 to 1-143 and Room 1-145 ***(study83 to study91)*****:** These are the infectious-diseases laboratories. The laboratories were all supplied with air from an evaporative cooler. The temperature after the evaporative cooler and the flow rate to each room was again measured and used in the program as input.

Room 1-7 ***(study93 and study95)*****, Room 1-9** ***(study92 and study94)*****:** The metabolic facilities were supplied with fresh air, and conditioning of the air was performed by ceiling-mounted cassette units. Each room was also equipped with a heater bank.

Sasol E ***(study96)*****, Sasol F** ***(study97)*****, Sasol N** ***(study98 and study99)*****, Sasol S** ***(study100 and study101)*****, Sasol W** ***(study102 and study103)*****:** The zones make up an administrative building of SASOL II located in Secunda. These specific zones were only serviced with mechanical ventilation.

It is quite clear that a wide range of building types and construction techniques are covered. A validation study of these buildings should thus help to achieve a high level of confidence in the applicability of the design tool in practice. The following section describes the 103 validation studies carried out in these buildings.

3.5 DESCRIPTION OF THE 103 VALIDATION STUDIES

A summary of the 103 validation studies is provided in Appendix B. The building zone names, location and date of each experimental study, and additional information are listed. Detailed information of each zone can be obtained on the attached disk. The building zone names correspond to the descriptions given in the previous section. The following discussion describes the modifications to obtain 103 case studies. Studies not described here were handled as described on the attached magnetic disk.

Forty-four studies were monitored with open windows. The natural ventilation rates in these studies are determined by the procedure given in ASHRAE [10], except for studies 71 to 74. The model presented by Rousseau [12] was used for these studies. The infiltration rates in the other studies are determined by means of equation 3.1. Six studies are listed as YN, indicating that the windows were opened and closed during monitoring. The window operation of these six studies is discussed later in this section.

The heat generation column lists forty-seven studies that included interior heat generation by means of small domestic heaters. Solar penetration occurred in most of the 103 studies and is thus not listed here under heat generation.

Twenty-five validation studies were performed on the experimental huts. Studies 1 to 4 were carried out in the huts without any change to the construction. In studies 5 to 8 the floors of the four huts were insulated with 25 mm thick expanded polystyrene. Studies 9 to 12 were again carried out in the buildings without any change to the construction, but the windows were open as opposed to the closed windows in studies 1 to 8.

In studies 13 to 16 the windows were again open, but the floors were insulated with 25mm thick expanded polystyrene. The floors were not insulated in studies 17 to 20, but the ceiling was insulated with 25mm thick expanded polystyrene. No floor or ceiling insulation was incorporated in studies 21 to 25, only the exterior colours of the buildings were modified. For studies 21 and 23 the roofs were painted black and the walls painted dark brown. The colour of the huts in studies 22, 24 and 25 was unchanged from the descriptions on the magnetic disk.

The validation studies carried out in the Negev Desert were a joint project between the University of Pretoria and the Desert Architecture Unit of the Jacob Blaustein Institute of Desert Research [13]. Primarily, the twelve studies differ only in window operation. For studies 35, 38 and 41, the windows were closed for the whole duration of monitoring. The windows were however open for the whole period in studies 37, 40, 43, and 71 to 73. For studies 36,39, 42 and 74 the windows were opened during the night from 20h00 to 08h00 and closed for the rest of the period.

Study 56 involving the factory also employs open and closed window operation. Although the building did not have windows that can open, some of the doors were kept open during the day between 07h00 to 19h00. Ventilation was achieved by means of these open doors and roof-mounted ventilators.

3.6 EVALUATION OF THE PROPOSED DESIGN TOOL

It is impractical to consider each case study individually when validating the new design tool. Criteria therefore need to be established to facilitate the evaluation of the tool. In this section several global parameters are defined (following the approach of Richards [1] and Van

Heerden [7]). This enables us to evaluate all the data at once, and to make comparisons between different models.

Five global thermal parameters are defined, i.e. the mean-, maximum- and minimum indoor temperature, the indoor temperature swing, and the phase shift between the measured and predicted indoor air temperatures. The mean indoor air temperature is simply the mean of the 24-hourly values. Maximum and minimum indoor temperatures are the comparison between the predicted maxima and minima relative to the measured values. The temperature swing is determined by taking the difference between the maximum and minimum indoor temperatures.

In this study the phase shift is determined by first calculating the difference in time between the measured and predicted indoor maxima. Secondly, the difference in time between the measured and predicted indoor minima are determined. The phase shift is then the mean of these two values. The phase shift lags when the difference is negative and leads if positive.

Figures 3.1 to 3.10 show the results of the global parameters for both tests. The correlation coefficients for each of these parameters are also presented on the respective figures. The correlation coefficients are a good indicator of how closely the predicted values relate to the measured data. However it does not give any idea of how that data is dispersed or the size of the error band. Average error and standard deviation for the mean temperature, temperature swings and phase shift were therefore also calculated. These results are provided in table 3.1

	Means		**Swing**		**Phase shift**	
	Average °C	**St. dev. °C**	**Average °C**	**St. dev. °C**	**Average hours**	**St. dev. hours**
Test 1	1.5	2.9	1.1	3.6	0.7	1.4
Test 2	0.4	1.5	1.5	1.8	0.3	1.4

Table 3. 1 - Average and standard deviation for the global parameter

Although global parameters can be considered representative of the thermal response of the indoor temperature, hourly values were also compared, but in an aggregated form. Detailed comparisons are provided in Appendix C. The cumulative error distribution of the differences between the hourly measured and predicted indoor temperatures of both studies are shown in Figure 3.11.

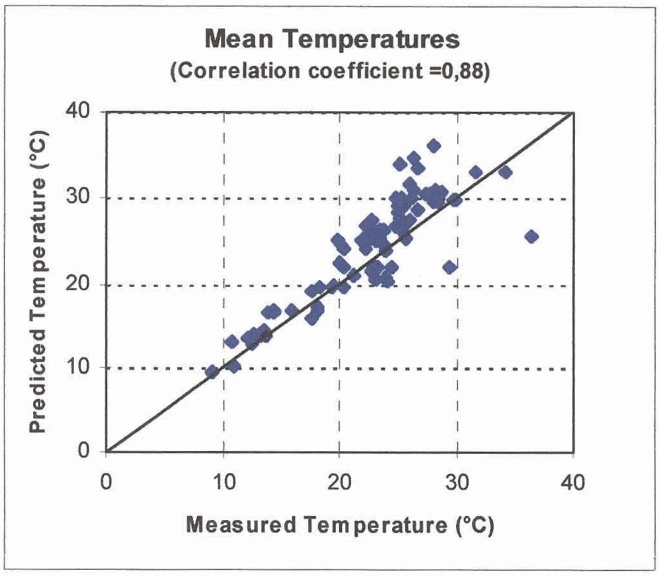

Figure 3.1 - Comparison between measured and predicted mean temperatures for Test 1.

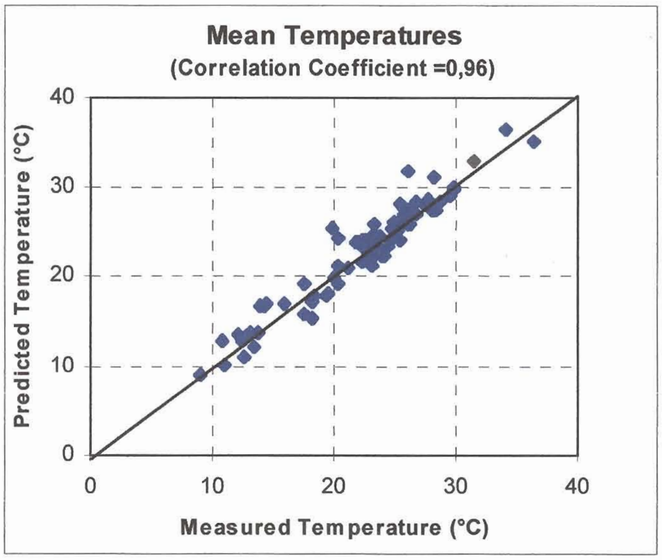

Figure 3.2 - Comparison between measured and predicted mean temperatures for Test 2.

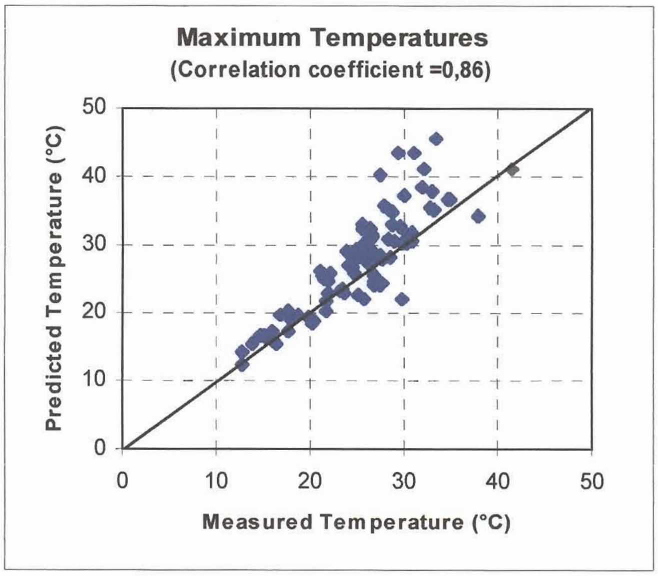

Figure 3.3 - Comparison between measured and predicted maximum temperatures for Test 1.

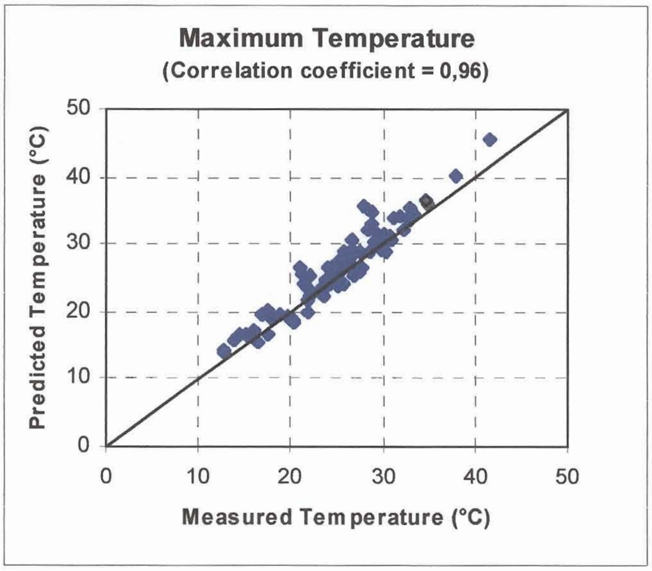

Figure 3.4 - Comparison between measured and predicted maximum temperatures for Test 2.

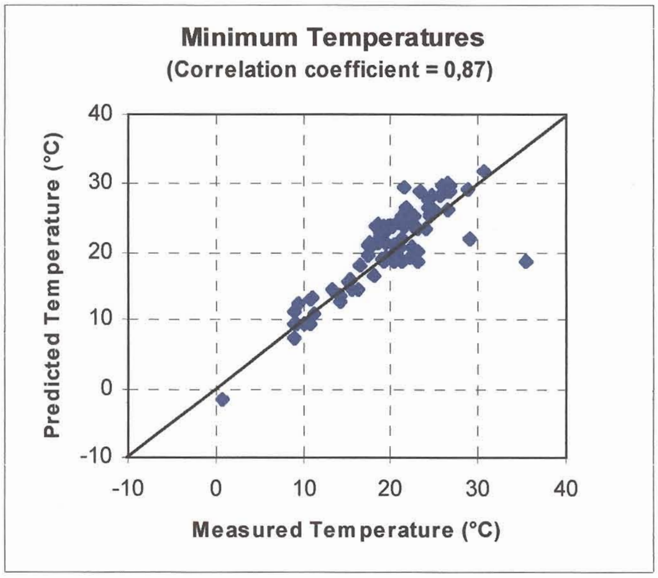

Figure 3.5 - Comparison between measured and predicted minimum temperatures for Test 1.

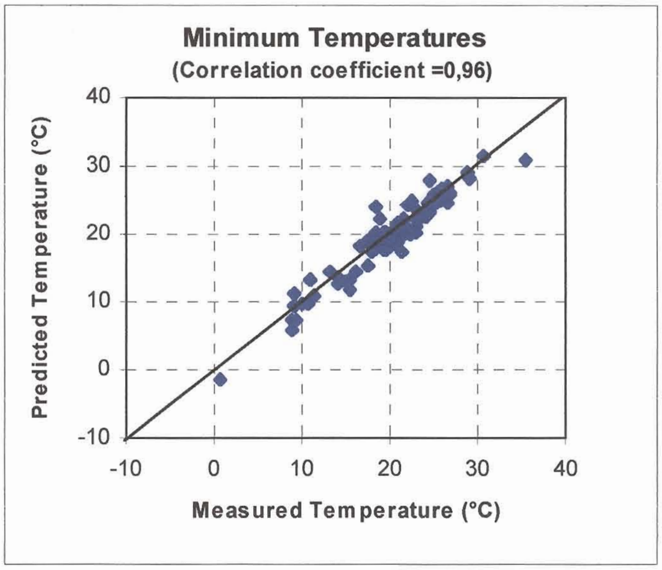

Figure 3.6 - Comparison between measured and predicted minimum temperatures for Test 2.

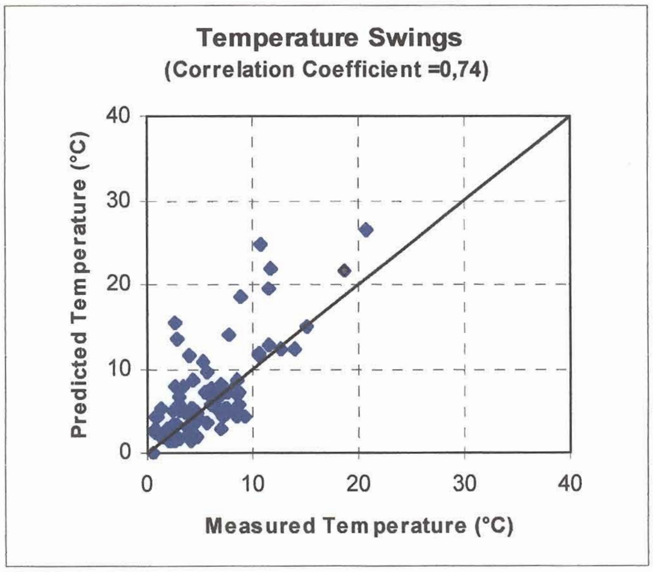

Figure 3.7 - Comparison between measured and predicted temperature swings for Test 1.

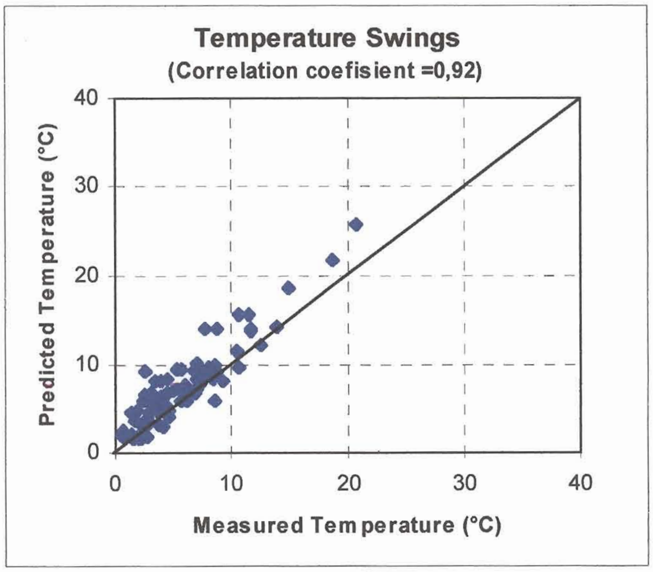

Figure 3.8 - Comparison between measured and predicted temperature swings for Test 2.

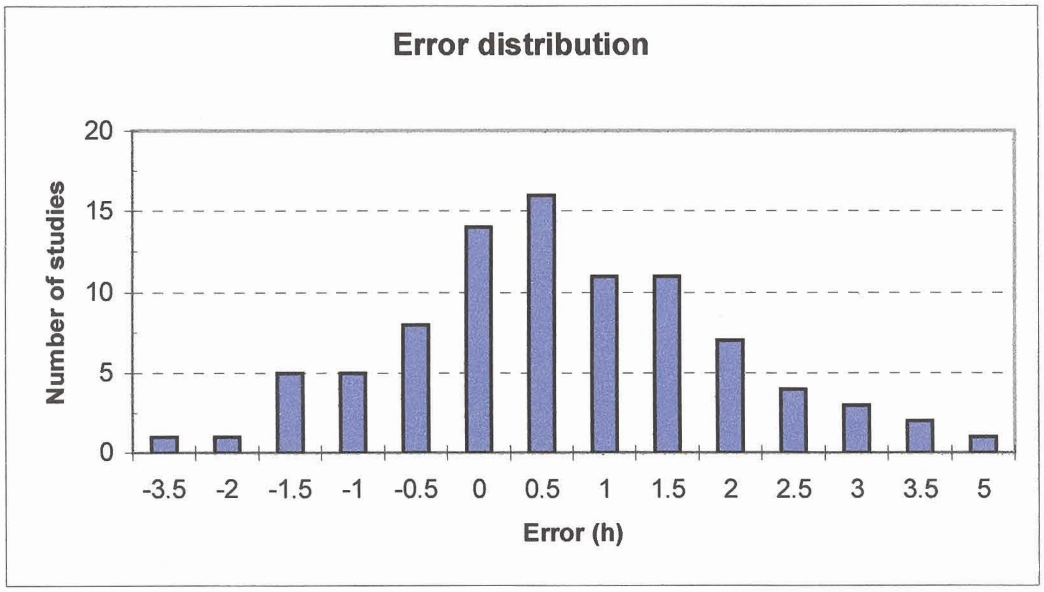

Figure 3.9 - Distribution of the indoor air temperature phase shift errors for Test 1.

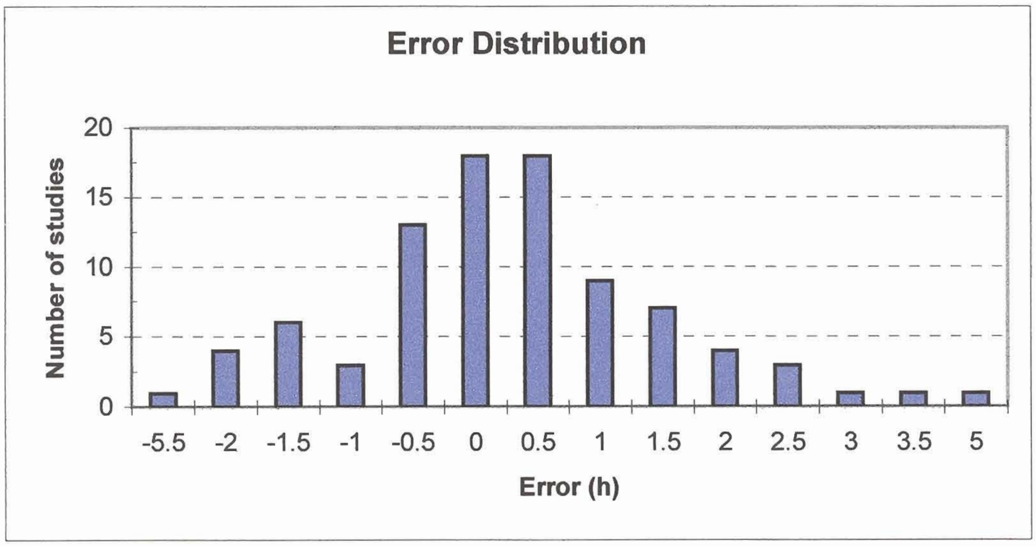

Figure 3.10 - Distribution of the indoor air temperature phase shift errors for Test 2.

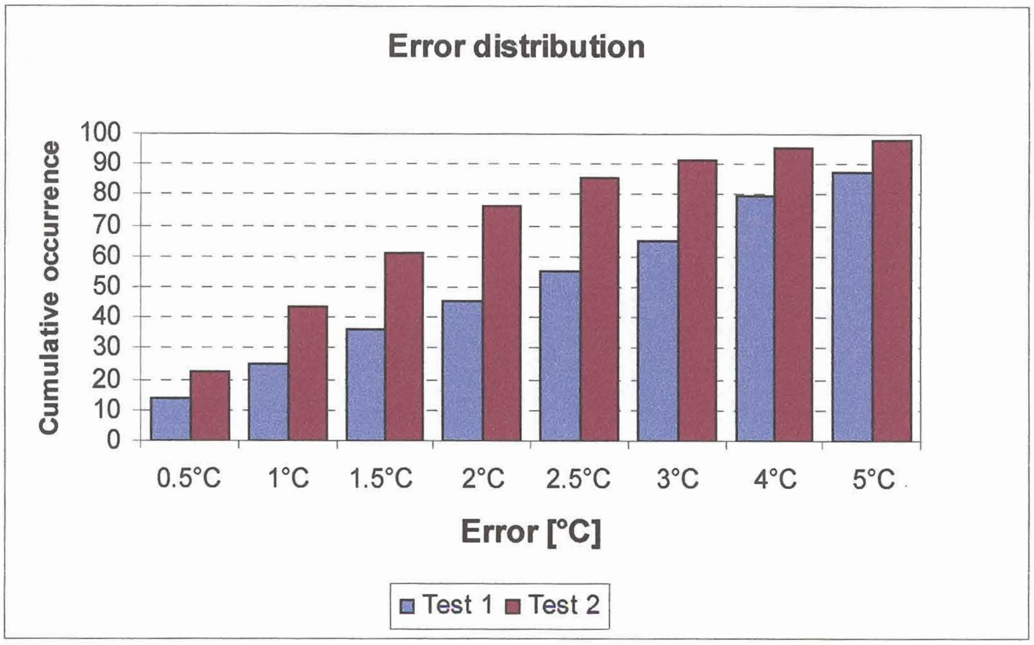

Figure 3.11 – Cumulative error distribution for the difference between hourly measured and predicted indoor air temperatures for both test cases.

It can be seen that there is a fair correlation between the mean, maximum and minimum temperatures in test 1. The temperature swing correlation however is not so good. This is to be expected since it depends on both the predicted minimum and maximum temperatures. It is therefore twice as sensitive to errors. Indoor temperatures were predicted within 3°C for 65 % of the time.

These results are quite acceptable considering the significant assumptions made for test 1. As expected, there is a marked improvement in the results of the second test. These results compare favourably with the actual data. Predicted indoor temperatures are within 2.5°C for 85 % of the time, and within 3°C for 90 % of the time. These results are exceptionally good considering that the tool was developed as a preliminary design tool. These results show that the new design tool, using the simplified building shell data, delivers satisfactory results and can thus be used with confidence.

The result of the first test seems a little disappointing at first. It should however be seen in context of the second test. In test 2, acceptable answers for a range of different ventilation and load profiles were obtained. It is thus safe to say that similar results would have been obtained if the default load and ventilation profiles, as used in test 1, were exactly the same as those of the actual buildings. The tool can therefore be used with the same confidence to evaluate the thermal performance of different building shells using the default load and ventilation values.

3.7 LIMITATIONS OF THE DESIGN TOOL

Fourteen of the case studies were identified as having multi-zone characteristics. The results of these studies were not included in the evaluation of the tool. As expected there were considerable differences between the predicted and actual temperatures. Differences in excess of 10°C were obtained for most of these studies.

This limitation is however usually only restricted to zones next to unconditioned areas such as kitchens, bathrooms and stairways. Major differences in temperatures however rarely occur. The new tool further aims to evaluate the total building shell rather than single zones. The average temperature of all the zones is therefore used. These variations must however be taken into consideration when sizing ventilation and air-conditioning equipment.

External or suspended floors are a second limitation identified. Currently the tool only makes provision for internal and ground contact floors. Seven case studies however had suspended or exterior floors. These floors were simulated as interior floors. Acceptable yet marginal results were obtained with this assumption. However, significant errors can be obtained if the climate differs significantly from the indoor air temperatures. This is a typical problem encountered in air-conditioned buildings.

3.8 CONCLUSION

The new thermal design tool was extensively tested using 103 actual building case studies. These buildings comprised of a wide range of different construction types, internal loads and ventilation requirements. Results gained from the tool using the simplified building shell were comparable to those obtained with more detailed design tools. The predicted temperatures were within 2,5°C for 85 % of the time.

It is clear that this tool can be used with confidence to evaluate and compare the performance of different building shells during the preliminary design stage. The results indicated that the tool also has the potential to be used in sizing HVAC systems. The current tool will need to be modified slightly to allow the user to provide detailed ventilation and load profiles as input. The tool will also need to address the two limitations identified during this validation.

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Chapter 4 A South African Energy Rating Scheme For Residential And Office Buildings

Building energy star rating schemes are seen as effective means of correlating building energy consumption with current design practices. Such a rating scheme can also be applied as a simple means of evaluating building thermal efficiency. Thermal efficiency of a building can be rated according to the maximum heating and cooling loads required for maintaining set temperatures for specific hours of the day. These ratings will however be dependent on climate and building type. An independent rating scheme was consequently developed for South African residential and office buildings.

4.1 INTRODUCTION

Reducing the energy consumption in buildings is one of the major concerns in modern building research and design. Design and retrofit guidelines and regulations are seen as one of the principle means towards eventually realising energy savings goals. Several countries have consequently already implemented such guidelines and regulations [1].

One of the items addressed in these guidelines is the thermal characteristics and therefore thermal performance of the building itself. These guidelines usually stipulate that the building construction must have an equal or lower overall heat transfer coefficient (U value) than a specified value or follows a more descriptive approach that achieves the same effect. However the thermal resistance of the building shell is not the only factor that influences the thermal characteristics of a building. Size, orientation, and glazing area must also be taken into consideration.

The abovementioned factors affecting the thermal characteristics of a building are mostly determined early in the design process. Preliminary design tools should therefore give the design team a simple means of evaluating the efficiency of their design. An energy star rating system is seen as an easy and marketable means of doing this [2,3,4]. Such a rating scheme was developed for rating the thermal efficiency of South African residential and office buildings.

4.2 SIMPLIFIED PRELIMINARY DESIGN RATING SCHEME

The most effective means of evaluating the thermal efficiency of a building is to determine the total annual energy consumption necessary to maintain a specified indoor temperature. This requires calculation and analysis of yearly data for the building. Designers however usually only have access to hot and cold design weather data.

Other drawbacks of this method are the complexity, and the time needed to perform this type of analysis. It is therefore rarely done during the preliminary design stage where its impact will be the highest. A simplified means of analysing building thermal efficiency early in the design process is thus required. For this reason a simplified rating system was developed.

Logic dictates that if the maximum required cooling or heating capacity is lower, then the annual energy consumed by the building to maintain a set indoor temperature will also be lower. The above analysis can thus be simplified from a yearly energy simulation to two quick heating and cooling load calculations, - one for a hot design day, and one for a cold design day.

The heating and cooling loads, normalised to building size, is given a rating compared to that of a suitable reference building. The smaller the heating and cooling load in comparison to that of the reference building the higher the rating of the building. This rating scheme can easily be incorporated into a simple, preliminary thermal design tool for architects.

4.3 REFERENCE BUILDINGS

The building type and application has a strong influence on the typical construction and utilisation of the building. The rating scheme must take this into consideration. Buildings are generally classified as places of assembly, health care facilities, offices, industrial, retail, or residential buildings. Of these, residential and office buildings form the bulk and collectively also have the highest energy savings potential. Therefore this study only focused on obtaining ratings for residential and office buildings.

4.3.1 Residential sector reference buildings

In South Africa, the residential sector can be sub-divided into low-income and medium- to high-income housing sectors. Providing formal low-income housing and subsidised electricity forms an integral part of the South African government's Reconciliation and Development Programme (RDP) [5]. Formal low-income housing is therefore likely to form the bulk of new residences being built. It would be very tempting to minimise the cost of low-income houses without giving any consideration to energy efficiency. However, this would very short-sighted as national energy resources would be wasted.

Low-income houses typically use lower quality building materials and cheaper construction techniques. As a result they will be less thermally efficient. From a cost perspective it is impractical to bring these houses up to a higher standard. These houses should therefore be rated on a separate scale that takes this into account. A separate reference building was thus used for low-income housing.

For the purposes of this study, the 53m^2 house as given in the Agrement booklet no.1 [6] was used as a typical formal low-income house. The 154m^2 house used by Piani [1] for establishing South African energy-savings guidelines, was used as a typical medium-income house. Figures 4.1 and 4.2 present the layout and sketch plan for both of these houses.

Occupancy density for the houses were calculated from

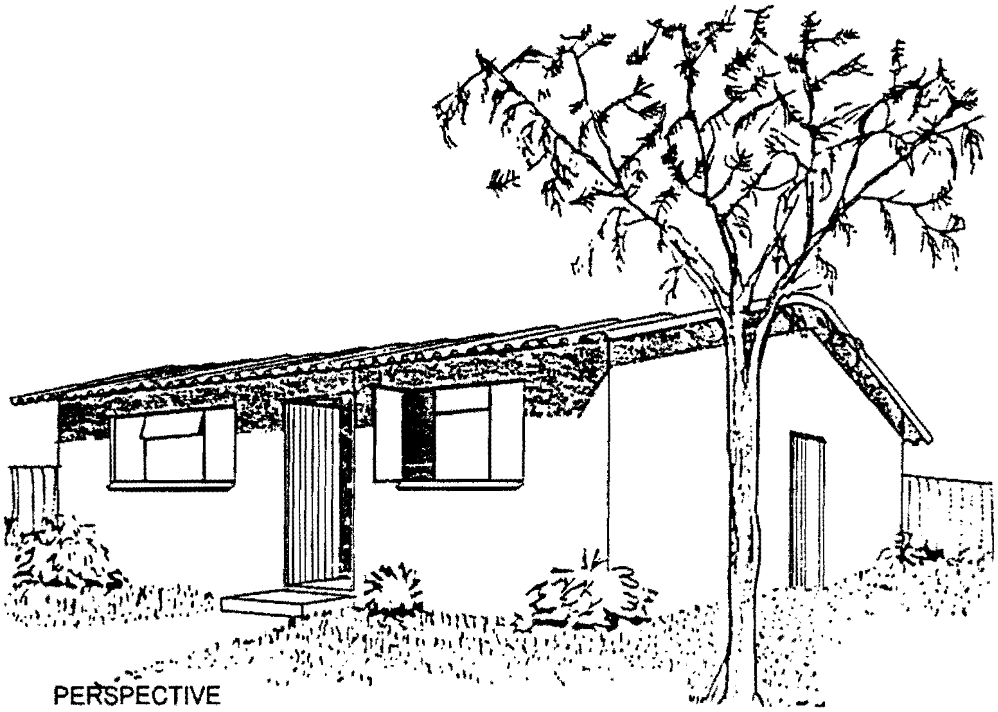
$$\text{Occupants} = 0.111 \times \text{floor area} \tag{4.1}$$

for low-income housing [7], and

$$\text{Occupants} = 0.026 \times \text{floor area} \tag{4.2}$$

for medium-income housing. It is further assumed that all the occupants are at home between 17h00 and 06h00. During the daytime, one third of the occupants were taken to be at home.

These assumptions are in agreement with a South African survey that indicates that the bulk of both these houses have an occupancy density of between 3 and 5 people [8]. Occupancy density and distribution for the reference buildings are shown in Figure 4.3.



PERSPECTIVE

WINDOW SIZES:
NC1 533 x 950
NC4 1 511 x 950
NC11F 2 000 x 950

NOTES:
1. CONCRETE FLOOR SLAB 75 mm THICK COVERED WITH HERMALLY CONDUCTIVE FLOOR FINISH.
2. UNISULATED CEILING OF 6 mm THICK GYPSON PLASTERBOARD.
3. GALVANISHED STEEL ROOF COVERING.
4. CAST CONCRETE BLOCK WITH PLASTER FINISH.

PLAN

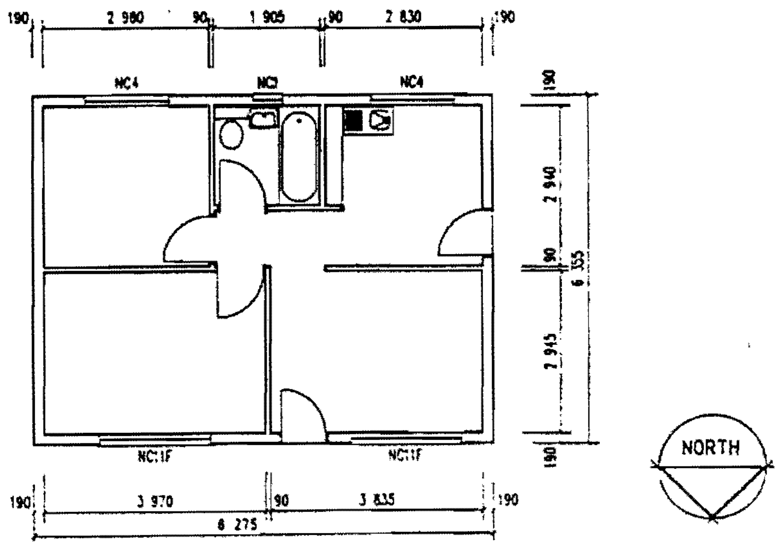


Figure 4.1 – Low-income residential building.

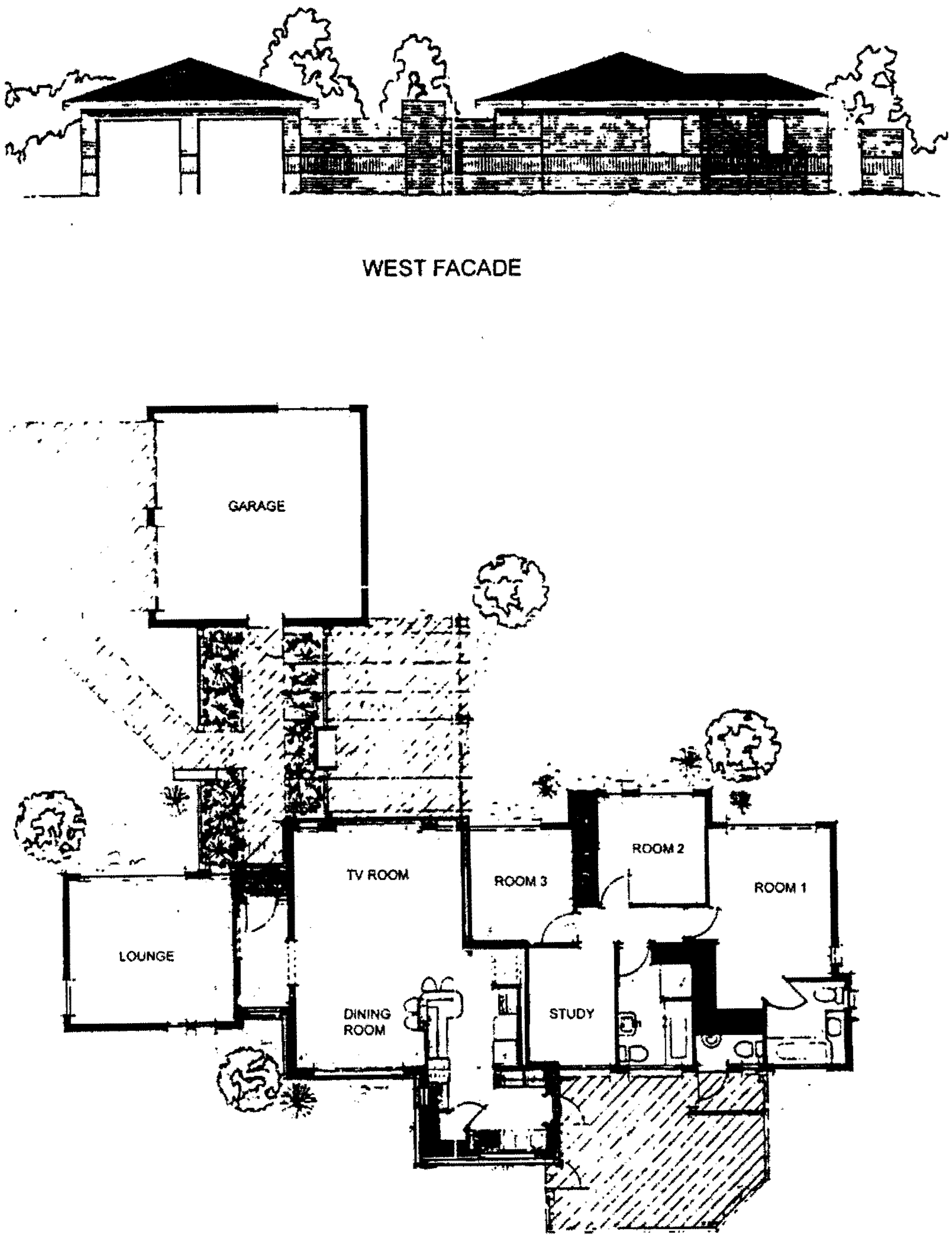


Figure 4.2 – Medium-income residential building.

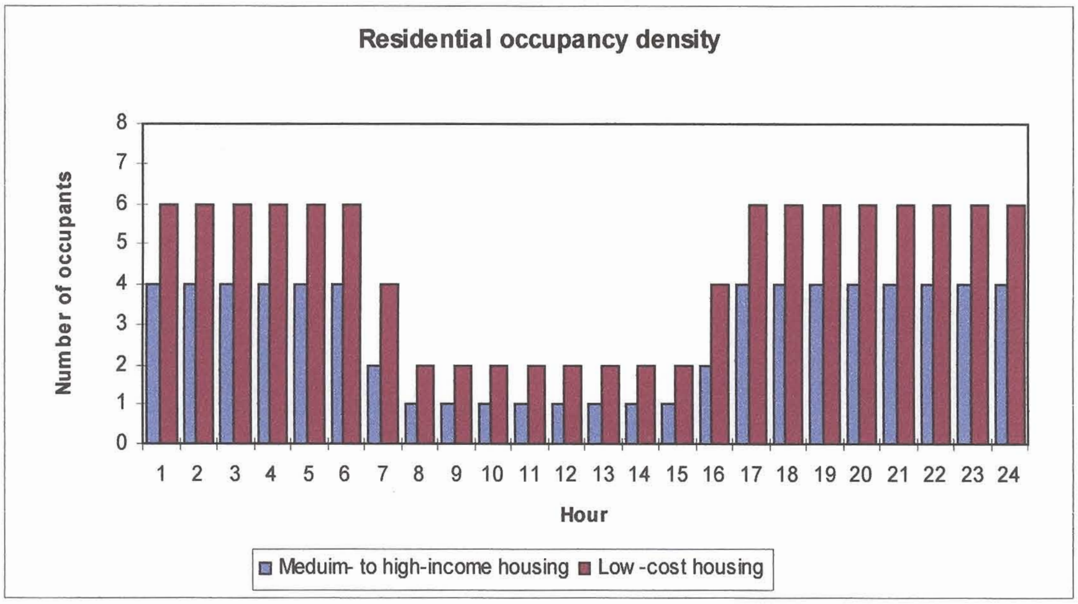


Figure 4.3 - Residential occupancy density.

Preparation of food was taken to be the only other significant contributing factor to the indoor load. Middle-income housing will typically have a higher load due to more appliances being used. Characteristic heat gain values for appliances are given in ASHRAE [9]. Based on the aforementioned assumption, the internal loads were calculated for the low-income and medium- to high-income housing respectively from

$$Internal\ \ load = 7 \times floor\ area\ \text{[W]} \tag{4.3}$$

and

$$Internal\ \ load = 8 \times floor\ area\ \text{[W]}. \tag{4.4}$$

These loads were taken to coincide with the typical time during which food is normally prepared namely, between 06h00 and 07h00, as well as from 17h00 to 20h00.

Most South African residential buildings are unlikely to have any form of mechanical cooling. The rating for these buildings is therefore based only on the heating load. Figure 4.4 represents a typical required winter indoor temperature profile based on comfort requirements. This profile was obtained from a study of 1500 houses [10]. Although the climate conditions for each region vary, the required temperature profile remains unchanged.

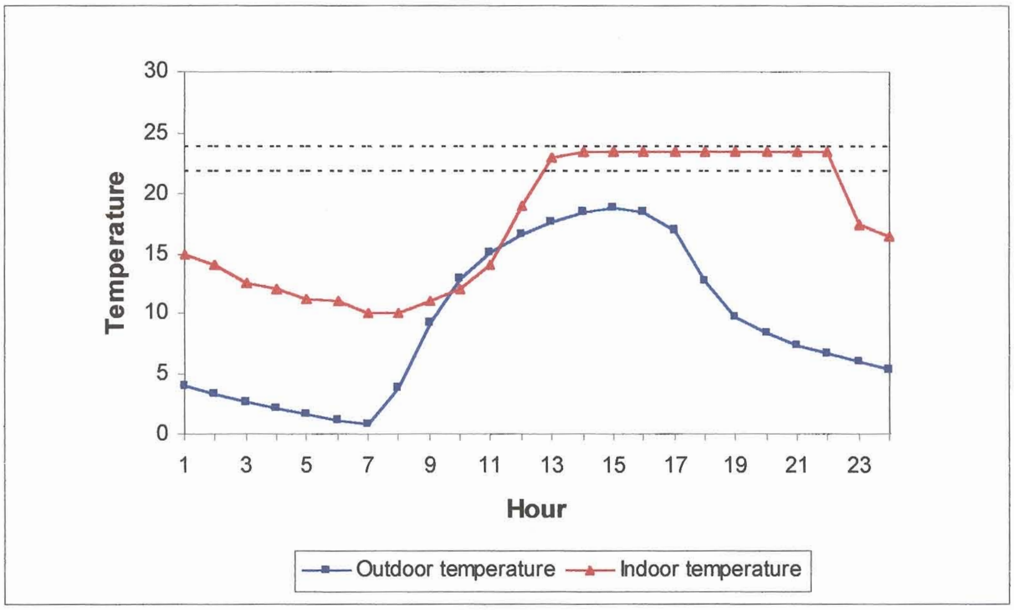


Figure 4.4 – Typical required indoor temperature profile [10].

In practice the suitability of this profile can be debated. In most cases only portions of a house is heated and only in the evening. It does however serve as a basis for comparing different buildings with the same indoor temperature requirements. Furthermore, from a design point of view the maximum heating requirements will occur early in the morning. For the reference buildings it was therefore assumed that heaters would also be used between 05h00 and 08h00 in the morning. Based on general accepted winter comfort norms, the indoor temperature in both low-income and medium-income housing was set to be 22°C.

4.3.2 Commercial sector reference buildings

Piani [1] identified two buildings on which he based his energy savings guidelines for South African commercial buildings. Architects and engineers sanctioned these buildings as good examples of energy efficient building design. One of the buildings serves as reference for passive building design. Passive design is commendable from an energy perspective, but not always practical. The other building applies to structures requiring air-conditioning. This building was consequently used as reference for the commercial sector.

The majority of office buildings are utilised between 08h00 and 18h00. Occupant and interior loads for the reference building were therefore assumed to occur only between these hours. Occupant density, outdoor ventilation and internal loads were calculated from:

$$Occupant\ \ density = 0.1 \times floor\ area\ \ [\mathrm{W}] \tag{4.5}$$

$$Ventilation = 10 \times occupants\ [\mathrm{L/s}] \tag{4.6}$$

$$Internal\ \ Load = 26 \times floor\ area\ \ [\mathrm{W}] \tag{4.7}$$

The internal load is taken to be 40% convective and 60% radiative [11].

Unlike residential buildings most office buildings also have some form of mechanical cooling system. The rating system for office building must therefore take summer as well as winter thermal efficiency into consideration. The required indoor comfort conditions were taken to be 24°C in the summer and 22°C in the winter.

The air-conditioning system however, will typically be operated for one hour before the occupants arrive. System operation for the reference building was thus set from 07h00 to 18h00.

4.4 CLIMATIC REGIONS

Climate plays a major role in the heating and cooling load requirements of the building. A meaningful comparison between buildings can only be made if they are subject to the same climatic environment. Different ratings are thus required for different climatic regions. Wentzel and Hodgson identified fifteen climatic regions for South Africa [12]. These regions are shown in Figure 4.5. An energy rating was consequently calculated for each of these regions.

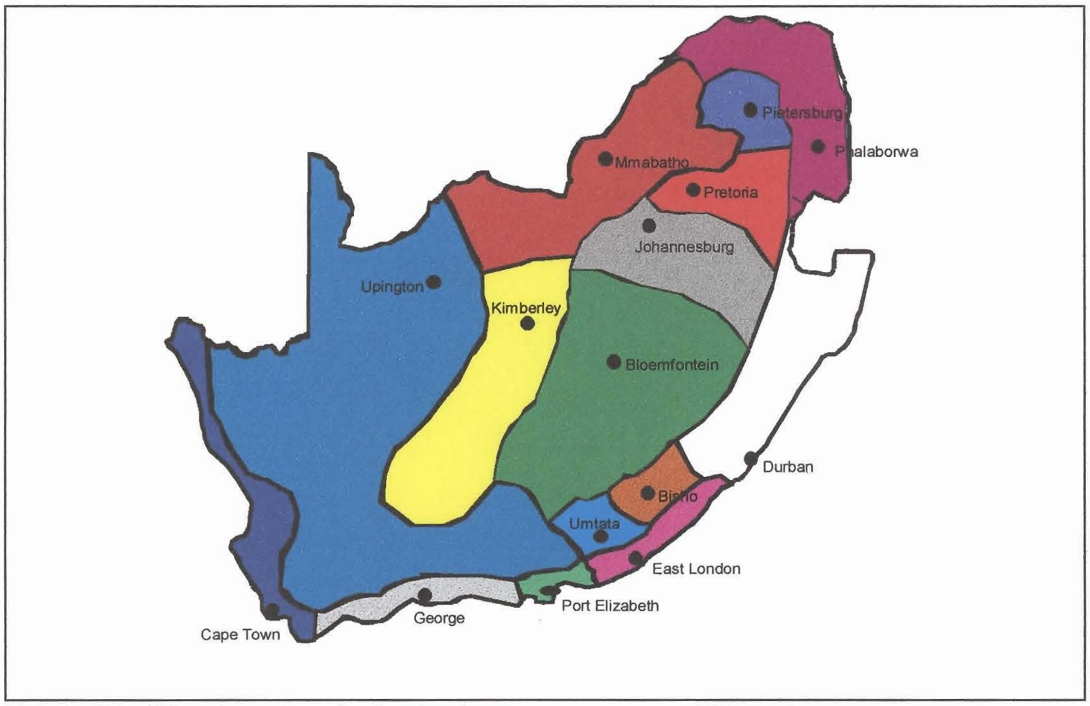


Figure 4.5 - Climatic regions for South Africa.

4.5 SCALING THE ENERGY RATING SCHEME

In order to ensure that it is possible to attain high energy ratings within realistic constraints it is necessary to scale the rating scheme. For this purpose a second set of reference buildings was used. These buildings used for scaling the rating system were chosen to reflect energy efficient buildings.

The residential sector rating scheme was scaled by adding roof insulation to the reference buildings. Studies show that this has a high impact [13,14]. The commercial sector was scaled using the other existing office buildings analysed by Piani [1]. These included buildings that apply expensive design considerations to reduce the load to less energy efficient designs. A suitable range could thus be obtained.

4.6 ENERGY RATING FOR SOUTH AFRICA

A rating scheme consisting of five points was developed using the above reference buildings as basis. The maximum sensible heating and cooling load of the reference buildings and buildings used for scaling were calculated for each of the climatic regions[1]. Latent load is not considered, as it is not influenced by the thermal efficiency of the building shell. These requirements are normalised using floor area. This is done in order to make the rating scheme independent from building size.

For office buildings the average of the normalised cooling and heating load is defined as the building load requirement. Both heating and cooling load are consequently taken into consideration simultaneously. The rating system for the residential sector is however based only on the heating system requirement, as these buildings usually do not have any mechanical cooling equipment.

The minimum requirement for one rating point was set to be the same as that of the reference building. A rating of five is allocated to buildings that have better characteristics than the buildings used to scale the rating scheme. The remaining points are divided evenly between these two extremes. Table 4.1 indicates the rating factor for the various building types and climatic regions of South Africa. To qualify for a particular rating, a building must have a normalised load lower than the first and not smaller than the second indicated numeral.

The rating for a new building is obtained by calculating its heating and cooling requirements under similar load conditions as those of the reference building. This implies that the same assumptions, with reference to occupancy periods and indoor conditions, are made. Internal load and occupancy are however adjusted relative to the building size. This is done using the above equations. A medium-income house, located in Pretoria, with an average heating load requirement smaller than 0.14 kW/m^2 and greater or equal to 0.12 kW/m^2 will for example have a rating of two.

[1] Climate data with a 10% probability was used.

Bisho						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.22–0.20	0.20-0.18	0.18-0.16	0.16-0.14	0.14 >
Medium cost housing	Load (kW/m^2 floor area)	0.16-0.14	0.14-0.12	0.12-.10	0.10-0.08	0.08 >
Office	Load (W/m^2 floor area)	72 – 68	68 – 64	64 – 60	60 – 56	56 >
Bloemfontein						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.24-0.22	0.22-0.20	0.20-0.18	0.18-0.16	0.16 >
Medium cost housing	Load (kW/m^2 floor area)	0.18-0.16	0.16-0.14	0.14-0.12	0.12-0.10	0.10 >
Office	Load (W/m^2 floor area)	90 – 83	83 – 76	76 – 69	69 – 62	62 >
Cape Town						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.19-0.17	0.17-0.15	0.15-0.13	0.13-0.11	0.11 >
Medium cost housing	Load (kW/m^2 floor area)	0.14-0.12	0.12-0.10	0.10-0.08	0.08-0.06	0.06 >
Office	Load (W/m^2 floor area)	59 – 56	56 – 53	53 – 50	50 – 47	47 >
Durban						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.15-0.13	0.13-0.11	0.11-0.09	0.09-0.07	0.07 >
Medium cost housing	Load (kW/m^2 floor area)	0.11-0.09	0.09-0.07	0.07-0.05	0.05-0.03	0.03 >
Office	Load (W/m^2 floor area)	47 – 44	44 – 41	41 – 38	38 – 35	35 >
East London						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.12-0.11	0.11-0.10	0.10-0.09	0.09-0.08	0.08 >
Medium cost housing	Load (kW/m^2 floor area)	0.09-0.08	0.08-0.07	0.07-0.06	0.06-.005	0.05 >
Office	Load (W/m^2 floor area)	43 – 41	41 – 39	39 – 37	37 – 35	35 >
George						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.18-0.16	0.16-0.14	0.14-0.12	0.12-0.10	0.10 >
Medium cost housing	Load (kW/m^2 floor area)	0.13-0.11	0.11-0.09	0.09-0.07	0.07-0.05	0.05 >
Office	Load (W/m^2 floor area)	51 – 48	48 – 45	45 – 42	42 – 39	39 >
Johannesburg						
Rating		**1**	**2**	**3**	**4**	**5**
Low cost housing	Load (kW/m^2 floor area)	0.21-0.19	0.19-0.17	0.17-0.15	0.15-0.13	0.13 >
Medium cost housing	Load (kW/m^2 floor area)	0.16-0.14	0.14-0.12	0.12-0.10	0.10-0.08	0.08 >
Office	Load (W/m^2 floor area)	69 - 64	64 - 59	59 - 54	54 – 49	49 >
Kimberley						
Rating		**1**	**2**	**3**	**4**	**5**
Low income housing	Load (kW/m^2 floor area)	0.22-0.20	0.20-0.18	0.18-0.16	0.16-0.14	0.14 >
Medium, income housing	Load (kW/m^2 floor area)	0.17-0.15	0.15-0.13	0.13-0.11	0.11-0.09	0.09 >
Office	Load (W/m^2 floor area)	102 - 92	92 - 82	82 – 72	72 – 62	62 >
Mmabatho						
Rating		**1**	**2**	**3**	**4**	**5**
Low income housing	Load (kW/m^2 floor area)	0.22-0.20	0.20-0.18	0.18-0.16	0.16-0.14	0.14 >
Medium, income housing	Load (kW/m^2 floor area)	0.16-0.14	0.14-0.12	0.12-0.10	0.10-0.08	0.08 >
Office	Load (W/m^2 floor area)	87 - 80	80 - 73	73 – 66	66 – 59	59 >
Phalaborwa						
Rating		**1**	**2**	**3**	**4**	**5**
Low income housing	Load (kW/m^2 floor area)	0.12-0.11	0.11-0.10	0.10-0.09	0.09-0.08	0.08 >
Medium, income housing	Load (kW/m^2 floor area)	0.11-0.09	0.09-0.07	0.07-0.05	0.05-0.03	0.03 >
Office	Load (W/m^2 floor area)	65 - 61	61 - 57	57 – 53	53 – 49	49 >

Table 4.1 - Energy rating factors for South African residential and office buildings

Pietersburg						
Rating		1	2	3	4	5
Low income housing	Load (kW/m^2 floor area)	0.20-0.18	0.18-0.16	0.16-0.14	0.14-0.12	0.12 >
Medium, income housing	Load (kW/m^2 floor area)	0.14-0.12	0.12-0.10	0.10-0.08	0.08-0.06	0.06 >
Office	Load (W/m^2 floor area)	66 - 62	62 - 58	58 – 54	54 – 50	50 >
Port Elizabeth						
Rating		1	2	3	4	5
Low income housing	Load (kW/m^2 floor area)	0.17-0.15	0.15-0.13	0.13-0.11	0.11-0.09	0.09 >
Medium, income housing	Load (kW/m^2 floor area)	0.12-0.10	0.10-0.08	0.08-0.06	0.06-0.04	0.04 >
Office	Load (W/m^2 floor area)	52 – 48	48 - 44	44 – 40	40 – 36	36 >
Pretoria						
Rating		1	2	3	4	5
Low income housing	Load (kW/m^2 floor area)	0.21-0.19	0.19-0.17	0.17-0.15	0.15-0.13	0.13 >
Medium, income housing	Load (kW/m^2 floor area)	0.16-0.14	0.14-0.12	0.12-0.10	0.10-0.08	0.08 >
Office	Load (W/m^2 floor area)	77 - 71	71 - 65	65 – 59	59 – 53	53 >
Umtata						
Rating		1	2	3	4	5
Low income housing	Load (kW/m^2 floor area)	0.22-0.20	0.20-0.18	0.18-0.16	0.16-0.14	0.14 >
Medium, income housing	Load (kW/m^2 floor area)	0.17-0.15	0.15-0.13	0.13-0.11	0.11-0.09	0.09 >
Office	Load (W/m^2 floor area)	70 - 66	66 – 62	62 – 58	58 – 54	54 >
Upington						
Rating		1	2	3	4	5
Low income housing	Load (kW/m^2 floor area)	0.22-0.20	0.20-0.18	0.18-0.16	0.16-0.14	0.14 >
Medium, income housing	Load (kW/m^2 floor area)	0.17-0.15	0.15-0.13	0.13-0.11	0.11-0.09	0.09 >
Office	Load (W/m^2 floor area)	106 - 96	96 - 86	86 – 76	76 – 66	66 >

Table 4.1 - Energy rating factors for South African residential and office buildings (Continued)

4.7 QUALIFICATION OF ASSUMPTIONS AND RATING SCHEME

Various assumptions regarding occupancy periods, indoor loads, ventilation and comfort requirements were made in obtaining the above ratings factors. In practice these assumed values might vary considerably from the actual values. This does however not affect the rating scheme since these parameters do not directly influence the thermal efficiency of a building and the same assumptions are applied to all the buildings being analysed. These factors were only included in the rating scheme in order to maintain a margin of realism

The abovementioned parameters do have a substantial effect on the heating and cooling requirements of a building. As the rating scheme is based on these requirements it was consequently necessary to include these factors so that calculated heating and cooling loads correlates with the total building requirement. An additional benefit of this is that the load calculations necessary for rating the building further provides useful information for the preliminary design of the heating, ventilating and air-conditioning system. To benefit designer in this manner the assumptions are based on general design rule-of-thumb values, comfort requirements and building regulations.

The building load requirements used as basis for this scheme were calculated using NewQuick, a building thermal simulation tool. This program was used as its building model has been extensively verified using actual building data [7,15]. The model therefore has an established track record and credibility. The calculated rating factors can thus be used with confidence. These are important factors if the rating scheme is to be accepted by the design community as a design standard.

4.8 CONCLUSION

A simple energy rating scheme was developed for assessing the thermal efficiency of buildings. It is based on the theory that if the building heating and cooling load is reduced, then the annual energy consumption will also decrease. Detailed energy estimation, required by some rating schemes, can thus be simplified to two design calculations. Using simple thermal analysis software it is easy enough for architects to use it to evaluate their designs.

The rating scheme consists of calculating the design day sensible cooling and heating requirement of the building. This is then compared to that of a reference building. The smaller the required building load in comparison to that of the reference building, the higher the thermal rating of the building. Building features such as size, orientation, glazing area and shading are taken into account with this rating scheme. This method improves on norms that only use the overall heat transfer coefficient as means of evaluating building thermal characteristics.

Housing designers, developers and builders in many other countries have used national or regional energy rating schemes very effectively as marketing tools in distinguishing their product from others with lower performance ratings. This has created a demand by the consumer to purchase a building with a low rating, knowing that he will benefit from lower energy costs and superior indoor climate.

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Chapter 5 Development Of A Simplified Preliminary HVAC System Selection Tool

Thermally efficient building design can greatly reduce the need for, and size of air-conditioning systems. Certain buildings will however always require some form of HVAC system. More often than not these systems are selected based solely on initial cost, or the designer's experience. This is however short sighted as the system choice largely influences the socio-economic success of the building. Ideally, the selection process should consist of a detailed performance analysis for various systems as applied to the building under consideration. The system with the best overall performance is the logical choice.

Detailed analysis is very time consuming and impractical, especially during the initial stages of design. A simplified, preliminary analysis can however be carried out by estimating system performance. This estimate is based on data and experience gathered from similar projects as well as general system information. The selection criteria used as basis for comparing the various systems is strongly dependent on the building owner or developers requirements. It is therefore essential that these requirements also be reflected in the selection process. This chapter discusses the development of a simplified comparison method and selection rating system into a preliminary selection tool.

NOMENCLATURE

R_i : System rating factor for design criteria i

F : Maximum allowable rating

W_i : Weighing factor for design criteria i

SR : System ranking factor

S_i : Screening factor for design criteria i

P_i : Allocated percentage point for design criteria i

n : Number of design criteria

5.1 INTRODUCTION

Ever since the energy crisis of the seventies, a lot of research has gone into improving the efficiency of buildings. As a result, various guidelines and thermal design tools have been developed. Using these tools in the design of new buildings can greatly reduce the need for air-conditioning systems or their capacity requirements. However, some buildings will still need an HVAC system in order to maintain acceptable indoor comfort levels.

Selecting the most appropriate system for these buildings is not a simple task. It can be challenging even for the most experienced designer. This is compounded by the fact that there is generally little or no guidance when it comes to choosing the right system for a given building. According to Clark [1], HVAC system selection is often given less thought than that of the carpet selection. He further states that in most cases selection is usually based on the lowest initial cost. In other cases, systems are selected simply because the designers are familiar with them or because they are commonly associated with that type of building.

Using only the above factors as basis for the final system selection is very short-sighted. HVAC systems have the single largest impact on the owning and operating cost of buildings. They are also frequently cited as one of the biggest sources of complaints from occupants. It is thus essential that these systems be selected and designed with great care.

Ideally, the optimum system choice is obtained by means of a detailed analysis [2,3]. This consists of calculating, comparing and contrasting the characteristics of various systems for each building. Such an analysis is time consuming, and it also requires information usually not readily available during the preliminary design phase. Detailed analysis is therefore impractical and uneconomical, especially during the early stages of design.

During the preliminary design phase the requirements of the building owner or developer are identified. These requirements influence the building structure, layout, aesthetics and overall building characteristic, which subsequently affect the system choice. It is thus essential that the selection process also be initiated during this phase. A simplified analysis and selection tool suitable for use during the early stages of design is therefore required

System analysis can be simplified for the preliminary design phase by estimating performance characteristics. These estimates are based on data and experience gathered from similar projects. Simple equations relating system characteristics to floor area and capacity can be obtained through regression analysis. Using these equations, an assessment of the impact of each system can be made without the need for detailed design calculations.

A preliminary selection tool can be obtained by applying these equations into simple numerical ranking and rating method [4]. A prototype of such a simplified selection tool was developed using a spreadsheet during this study. Typical generic air-conditioning systems and selection criteria were identified and incorporated into the selection tool.

5.2 THE NEED FOR AIR-CONDITIONING

It is possible to design buildings that do not require elaborate HVAC systems. Indoor comfort can be obtained passively by means of natural ventilation or by other architectural features built into the building [5,6]. Passive design features are however not always sufficient to maintain indoor comfort. Certain building designs, applications, and buildings located in harsh climatic conditions need air-conditioning.

Buildings that are typical candidates for air-conditioning are as follows [7]:

- High-rise buildings;
- buildings that have extensive glazing areas;
- buildings located in areas where the windows cannot be opened due to dust, noise, etc;
- buildings with high internal loads or occupant density;
- deep plan buildings with internal heat gain.

5.3 AIR-CONDITIONING SYSTEMS

There are a multitude of different system types and configurations available for use by air-conditioning designers. It would consequently be impracticable to define all the systems and their variations. These systems can however be generically classified according to their method of operation. Systems are primarily classified as all-air systems, air-water systems, all-water systems or direct expansion or unitary systems. Each group has distinct advantages and disadvantages [2,8,9,10,11].

5.3.1 All-air Systems

Description

These systems provide the required sensible and latent cooling, heating and humidification via air supplied to the zone. No additional cooling is done in the zone. In some cases however there can be some form of reheat present in the zone. These systems are generally central systems.

Both air treatment and refrigeration plants may be located some distance from the conditioned space. The refrigeration and air treatment plants are connected either through refrigerant or water piping. A system of ductwork and diffusers conveys the conditioned air to the zones.

These systems can further be classified as either:

- *constant or variable volume* - depending on whether the system changes the supply temperature or the amount of air to control load variances;
- *air or water cooled* - indicating how heat is rejected from the refrigeration plant;
- *full fresh or re-circulation* - depending on whether the system supplies only fresh air to the zone or a mixture of recycled and outdoor air.

Advantages

- These systems have little or no equipment within the occupied areas that require maintenance. They therefore also take up little or no space within the tenant's area.
- Noise levels are low since the equipment is located away from the occupied areas. In addition, these systems can also incorporate a wide range of vibration and noise control systems.
- Keeping piping, electrical and mechanical equipment, wiring and filters away from occupied areas reduce the potential risk of injury to occupants or damage to furnishings or processes.
- Equipment is generally durable and of a high quality as the system contains only a few air-handling units.
- These systems lend themselves to good filtration and outdoor air distribution.
- Free cooling or the use of outdoor air can be incorporated relatively easily and at low cost.

- A wide choice of zoning, flexibility and humidity control under all operating conditions is available.
- These systems are well suited for applications that require specialised makeup air quantities such as positive or negative pressurisation.
- All-air systems adapt well to winter humidification.
- Using high-quality controls it is possible for these systems to maintain the strictest operating conditions of ±0.15°C dry-bulb, and ± 0.5% relative humidity.

Disadvantages

- These systems require large additional spaces for ducting. Required ceiling voids increases the height of the building and building cost. Usable floor space is also smaller, as space is required for the duct risers.
- Close co-operation is required between architect and engineers to ensure that terminal devices are accessible.
- Air balancing, particularly on large systems, can be difficult.
- These systems cannot cope with large changes in space load and function.
- Adding capacity is both costly and difficult.
- It is difficult to accurately bill tenants for air-conditioning costs.
- After-hours operation for single occupants can be costly. This is also true if sections of the building are unoccupied but they still contribute to the air-conditioning load.
- Breakage can effect large areas.

5.3.2 Air -water systems

Description

Air-water systems use both water and air to condition the indoor spaces. Air and water are conditioned by means of a central plant and then supplied to the different building zones. The conditioned air serves to balance the normal building load, satisfy the ventilation requirements, and provide humidity control. This air is called the primary air.

The water on the other hand accounts for the zone specific load requirements and fluctuations. The water supplied to each zone is called the secondary water. Electric heating may be present in some cases instead of a hot water coil.

Two basic types of air-water air-conditioning systems exist namely, induction units and fan-coil units. These units can be arranged in a multitude of configurations from ceiling mounted units to floor units. They can basically be classified as either being:

- *air or water cooled* - indicating how heat is rejected from the central refrigeration plant;
- *two-, three- or four pipe systems* - indicating the number of water pipes connecting the zone coils with the central plant.

Advantages

- These systems provide individual room temperature control at a reasonable cost. They also cater for individual preferences by adjusting each thermostat of each zone coil.
- Air-water systems take up less building space. The air distribution system is smaller and therefore requires less ceiling and vertical shaft space for ducting. The size of the central air-handling plant is also smaller as less air needs to be conditioned centrally.
- Dehumidification, filtration and humidification are performed at a central location away from the conditioned spaces.
- Routine maintenance in the zones is generally limited to temperature controls and cleaning of lint screens. Induction units require infrequent cleaning of the induction nozzles, and fan coil units require servicing and lubrication of the fan and motor.
- Minimum cross contamination of air from different areas occurs since each zone uses its own air for re-circulation.

Disadvantages

- These systems require some space in the tenants' area for the induction or fan-coil units. A certain amount of maintenance therefore is also required within the tenants' area.
- These systems are generally limited to perimeter spaces. They are also not applicable for use in spaces with high exhaust requirements unless supplementary ventilation is supplied.
- The controls and electrical reticulation required for these systems are more complex.

- Filtration of the air inside the conditioned space is not very good. This can reduce the efficiency of the induction and fan-coil units. The lint screens of the units must therefore be cleaned regularly. Outdoor air, usually supplied as primary air, can however be filtered efficiently.
- Primary air is usually supplied as a constant volume with no provision for shutoff. Managers can not turn off the air-conditioning in unutilised spaces to save energy.
- Noise levels experienced inside conditioned areas can be higher than that for all-air systems.
- Control tends to be more numerous for many all air systems.
- Initial costs of four-pipe systems are generally higher than those of all-air systems.

5.3.3 All -water systems

Description

All-water systems are basically the same as air-water systems, the only difference being that no conditioned air is supplied to the zones. Outdoor air requirements are either provided for by windows or in some cases by the use of through-the-wall units. One of their main uses is as hot water radiant or panel heaters. These systems can also be further sub-classified in the same manner as the air-water systems.

Advantages

- The biggest advantage of these systems is that they do not require any ducting. Loss in usable floor area and ceiling height is therefore kept to a minimum.
- They provide individual room control while still retaining some of the advantages of a central system.
- In retrofitting existing buildings it is often easier to install piping and wiring rather than ducting.

Disadvantages

- These systems have more units that require maintenance. Most of this work must be done within the occupied spaces.
- Some of the units require costly and difficult drainage systems. This is especially essential for units working at low dew-point temperatures.

- These systems do not make provision for required outdoor ventilation. Ventilation is usually provided by open windows or wall mounted fans. Stack effect and wind can therefore affect ventilation.
- Summer room humidity levels tend to be high

5.3.4 Direct expansion or unitary systems

Description

The main characteristics of these units are that they consist of integrated factory assembled components. The components of these self-contained units are matched and assembled to achieve specific performance objectives. These units are therefore only available in pre-set capacity and performance increments, such as the sensible heat ratio for a given room condition, or litres of air per second per kilowatt of refrigeration [9].

These limitations however are offset by units that are cheap and easy to manufacture with high standards of quality control. There is also a wide variety of types and configuration available. These units can also be sub-classified further according to how they look and function. They are typically one of the following:

- *Split units* - these systems are split into indoor and outdoor units. Refrigerant piping connects the two units;
- *Window or through-the-wall console units* - the systems are self contained air-conditioning systems incorporated into a small package.
- *Rooftop packaged units* - these units consist of larger self-contained units. They are usually installed on the roof of a building. As with all-air systems, these units also supply conditioned air to the zones. The length of ducting is however restricted.

Advantages

- Individual room control by tenants is simple and inexpensive.
- Heating or cooling can be provided independently from other spaces.
- Factory assembly of the units allow for improved quality control, reliability, and certified performance data and ratings.
- Easy installation due to repetitive tasks and manufacturers instructions.

- The systems are generally readily available. This reduces problems in scheduling the ordering and delivery of equipment and less co-ordination is required during the building stage.
- These systems are simple to use and therefore do not require trained operators.
- Breakdown only affects a small area.
- Energy costs can be metered directly to each tenant. Units in unutilised areas can be switched off.
- Less mechanical and electrical space is required than for central systems.
- Initial costs are usually low.

Disadvantages

- Systems are limited in available airflow and distribution as well as cooling coil and condenser sizes.
- These systems are generally not suited for close humidity control. Some units designed especially for computer rooms etc. can however accomplish this.
- They have a higher operating and owning cost than central systems.
- Units have a relatively short life (± 8 years in dry areas and 4 to 5 years in coastal areas [8]).
- Overall appearance of systems can be unappealing.
- Noise levels within the zones can be high and unacceptable.
- Outdoor air supply requirements need to be addressed by other means. Usually by window operation. These systems also have limited filtration options.
- Building depth is severely limited. (Maximum depth of office is 4 to 4,5 metres [8]).
- Condensation leakage from the units can be a problem.
- Maintenance is required in the tenants' areas and can be difficult to perform.

5.4 SELECTION GOALS AND CONSTRAINTS

In theory, it is possible to successfully apply every system to any building. In practice however, design goals and constraints limit system choice. The financial and functional objectives and criteria of the building owner or developer dictate design goals, and constraints normally comprise of geographical and physical building limitations.

Typical design goals and constraints considered are [2,9,12,13]:

- Available space for the system;
- performance requirements;
- indoor air requirements;
- initial costs;
- running costs;
- aesthetics;
- flexibility;
- maintainability.

5.5 SYSTEM SELECTION

Identifying and rating the relative importance of the above design criteria is the first step in selecting a system. These factors are however interdependent and affect not only one another but the other building design disciplines as well. Sometimes it is necessary for a compromise to be reached between the various design goals and other design disciplines. It is therefore crucial to involve the whole design team in the selection process

The rated design goals and constraints are used as basis for comparing and weighing the various system strengths and weaknesses against each other. Suitability of a system depends on how well its' characteristics match those of the rated design criteria [9]. System characteristics may vary depending on building size, climate and load conditions. A detailed system analysis is therefore required for each new building.

New integrated building and system simulation tools can greatly reduce the effort required for detailed system analysis [14,15]. These tools however still require a reasonable amount of time and skill to use. They also do not make provision for explicitly involving the entire design team in the selection process. A simplified selection tool that incorporates the design goals and constraints of the whole design team is required. Such a tool can be used to screen systems, thereby effectively reducing the number of systems to be compared.

5.6 EXISTING SELECTION TOOLS AND METHODS

Expert systems [16,17] for selecting HVAC equipment and numerical ranking methods [4,18,19] have in the past been applied to aid designers in selecting equipment. Expert systems use heuristic rules and if-then statements to make design selections. These rules and statements are based on knowledge and experience gained from several experts in the field. A typical example of such a tool was developed by ASHRAE for research project RP-642 [13,20]. Expert systems however have certain inherent problems.

Obtaining and encoding the knowledge from experts is difficult. The decisions made by these systems are also only as good as the experts that compiled the rules. Furthermore, these systems are restricted to the information originally encoded into the knowledge database. They can consequently become obsolete, as advances are made in technology or if new and different air-conditioning systems need to be added. A certain amount of programming will therefore be required to maintain the program. Expert systems are therefore generally too complex to be maintained and used by the majority of designers.

Numerical ranking methods on the other hand are simple and straightforward design evaluation techniques [4,18,19]. These methods typically use weighted system rating factors to rank systems in order of suitability. Systems are given rating factors according to how well their characteristics match certain design criteria. A weighing factor is assigned to each of the criteria based on its relative importance. The system with the highest overall weighted rating is ranked as the most appropriate system choice.

These methods also have some limitations that need to be addressed. Some of these methods do not account for all the design criteria or include an explicit method for involving the whole design team [4]. These methods may also be biased toward certain systems. This is due to the assigned rating factors being based solely on the experience and judgement of the system designer. Another problem of the numerical ranking methods is that it requires a detailed system analysis to be completed in order to rate varying factors, such as spatial requirements. It is therefore not ideally suited as a preliminary design tool.

5.7 A SIMPLIFIED PRELIMINARY SELECTION TOOL

A simplified preliminary design tool can be obtained by combining the positive features of both expert systems and numerical ranking methods. This is achieved by using a numerical ranking method as an expert shell. Such a tool will retain the simplicity of the numerical ranking method. Rating factors will however not only be based on one designer's judgement, so prejudice towards certain systems can thus be reduced. Expert knowledge can be used to rate varying system characteristics without the need for a detailed system analysis.

Some system characteristics can be estimated from published system information as well as experience gained from completed projects. Using this information and regression analysis it is possible to obtain simple equations that relate various system characteristics to floor areas and cooling loads. Characteristics such as cost, space requirements, and weight can be predicted by applying these equations for each different system type being evaluated. This is illustrated in more detail in Chapter 6.

The rating factors, required by the selection tool, can be obtained from the estimated system design characteristics. This is done by normalising each property by using the system with the worst characteristic as a basis. A rating factor for initial cost, for example, is obtained as follows:

$$R_i = F - \frac{(Estimated\ \ Initial\ \ Cost\ \ of\ \ system)}{(Maximum\ \ Estimated\ \ Initial\ \ Cost)} \times F \qquad (5.1)$$

Non-quantifiable criteria, such as aesthetics, are rated based on feedback from various experts. In the absence of such data, the method as described by Scanlon [4] can be used. This consists of assigning the maximum rating to the system that best fulfils the desired design goal. The remaining systems are then rated relative to this system. Rating factors only indicate how well a specific system is suited towards a particular design goal or constraint. The importance of achieving this criterion however varies for each different building.

Weighing factors are used to adjust the rating factors so that those criteria, which are more important, have a greater influence. Weighing factors must be obtained for each design criteria. These factors are dependent on the requirements identified by the design team and owner or developer. These factors must therefore be obtained through direct communication with the entire design team. This is done by means of simple questions structured to gauge the design preferences, goals and constraints.

For each system being considered, a total system ranking is calculated by adding the product of the weighing and rating factors of each of the design criteria:

$$SR = W_1 R_1 + W_2 R_2 + \ldots + W_n R_n \qquad (5.2)$$

Suitability of the systems can be compared once a ranking factor for all the systems has been calculated. The higher the system ranking value, the better the systems fulfils in the design criteria. Using this method it is possible to identify the top two or three systems. Only these systems need to be evaluated in greater detail. In some cases the ranking can indicate that one system has an overwhelming advantage over the others. Detailed calculations are therefore only required for this system.

A preliminary selection tool was developed and implemented in a spreadsheet application to demonstrate the use of this model. Spreadsheet applications are ideal for this type of problem since they are simple and already used by many designers. Changing or updating the knowledge database is a simple task that does not require any programming skills. The rest of this chapter and chapter 6 deals with gaining the domain specific knowledge required for the tool. The potential systems and the design goals and limitations are identified for application in the selection tool prototype.

5.8 SYSTEMS CONSIDERED FOR THE TOOL

The aim of the selection tool is to provide designers with an aid in selecting the appropriate air-conditioning system during the preliminary stages of design. Detail construction and layout of the systems are therefore not required. The generic system types previously identified can thus be used.

The South African climate is mostly hot and dry. Buildings consequently require cooling for most of the year. The selection tool therefore focuses on selecting a cooling system. The methods used to develop this tool can however be applied to incorporate other or new systems.

The following air-conditioning units are defined for this tool:

1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.
4. All-air, variable air temperature, economiser system and air-cooled refrigeration plant.
5. All-air, dual duct system with water-cooled refrigeration plant.
6. All-air, dual duct system with air-cooled refrigeration plant.
7. All-air, variable volume, economiser system and water-cooled refrigeration plant.
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.
9. Four-pipe system with air-cooled refrigeration plant.
10. Four-pipe system with water-cooled refrigeration plant.
11. Two-pipe system with air-cooled refrigeration plant.
12. Two-pipe system with water-cooled refrigeration plant.
13. Split systems.
14. Window units.
15. Through-the-wall console units.
16. Packaged rooftop units.

5.9 DESIGN CRITERIA

The design criteria used for the selection tool prototype are based on the typical goals and constraints previously identified. The relative importance of the different design criteria is obtained by allocating 100 percentage points to be distributed among the criteria. These points are awarded to each criteria based on proportional significance, as determined by the entire design team. This value is expressed as the goal factor.

Constraints placed on the design can limit the use of certain systems. Systems that require space for ducting, for example, can be eliminated if the building design does not allow for this. Suitable questions were identified to gauge these absolute limitations. Table 5.1 lists typical questions with their possible answers and respective screening factors.

Based on these questions, a screening factor between 0 and 1 is allocated to each of the corresponding design goals. A value of 1 indicates extreme importance, while 0, indicates that no absolute requirement is imposed on the design goal. Design criteria not affected by absolute limitations, such as cost and cooling load per zone, are assigned a screening factor of one.

The screening factor of each design criterion is increased relative to its allocated percentage point. The weighing factor for each criterion is the adjusted screening factor, expressed as a percentage of the total of all the adjusted values.

$$W_i = \frac{S_i \times (1 + P_i)}{\sum_{i=1}^{n} S_i \times (1 + P_i)} \times 100 \qquad (5.3)$$

5.10 CONCLUSION

Selecting HVAC systems greatly influences the future success of a building. It is however not a trivial task. The designer must select from the myriad of options available, a system that best suits the requirements and limitations imposed on the building. This often requires some form of compromise to be reached between the different design disciplines. To effectively achieve this, it is necessary to get the whole design team involved in the selection process. This is especially important during the preliminary design stage.

A simplified analysis and selection tool suitable for use during the early stages of design can be of great assistance to designers. A prototype of such a tool was developed by combining the simplicity of numerical ranking methods with the proficiency of expert systems. This tool aids the designer in establishing and ranking the design goals and limitations in order of importance. Based on this information, the tool suggests one or two systems that can be analysed in more detail.

The use of such a preliminary tool promotes the concept of integrated building design. It incorporates the whole design team in the selection of the air-conditioning system. This in turn promotes more confidence in the validity of the system choice and it reduces the need for detailed analysis of a multitude of systems. Other building design disciplines will also be better equipped to make provision for the system, the end result being a more effective design effort.

Ref.	Design Criteria	Typical answers and Relative Screening factor
A	**Building Restrictions**	
A1	Is there enough floor space available for equipment. (Including rooftop)?	Yes = 0 /Restricted =0.5 /No = 1
A2	Is there sufficient space for the secondary heat transfer system i.e. ducting and chilled water piping?	Yes = 0 /Restricted =0.5 /No = 1
A3	Impact of system weight on building structure?	No = 0 /Yes = 1
A4	System required for both interior and perimeter zones, or only perimeter zones?	No = 0 /Yes = 1
B	**Aesthetic limitations**	
B1	Is aesthetically allowable to have equipment located in the zone?	Yes =0 /Limited = 0.5 /No = 1
B2	May window mounted units be used?	Yes = 0 /No = 1
B3	May inlet grilles or condensers form a major feature of the facade?	Yes = 0 /No = 1
B4	Can rooftop or external enclosure be aesthetically incorporated in design?	Yes = 0 /No = 1
C	**System requirements**	
C1	Noise level in the zone critical? (i.e. sound stage vs. Workshop area)	No = 0 /Intermediate = 0.5/Yes = 1
C2	Will there be skilled maintenance and system personnel?	Yes =0 /No = 1
C3	Is regular in-zone maintenance allowed?	Yes = 0 /No = 1
C4	Individual control of setpoint and temperature required?	No = 0 /Yes = 1
C5	Do the zone loads differ greatly?	No =0 /Yes = 1
D	**Air quality and flow restrictions**	
D1	Is the filtration of air important? (I.e. clean room environment)	No = 0 /Intermediate = 0.5 /Yes = 1
D2	High amounts of air contaminants present in the zone? (i.e. Laboratories)	Yes = 0 /limited = 0.5 /No =1
D3	Specialised make up air required? (i.e. room pressurisation)	No = 0 /Yes = 1
D4	Does the building have any other means of providing outdoor air?	Yes = 0 /No = 1
D5	Stringent humidity control important?	No = 0 /Intermediate = 0.5/Yes = 1
E	**Building management requirements**	
E1	Must the system be manageable from a central control room?	No = 0 /Yes = 1
E2	Is it important to cut of the supply to unused zones? (i.e. unused hotel rooms)	No =0 /Yes = 1
E3	Is separate zone electrical billing required?	No =0 /Yes = 1
E4	Is the layout of the zones and loads going to vary in the foreseeable future?	No = 0 /Yes = 1
F	**System cost (Initial cost or life-cycle cost)**	**1**
G	**Preliminary design restrictions**	
G1	Required cooling capacity per zone?	1
G2	Is the system located in a dry or humid climate?	Dry = 0 /Humid = 1

Table 5.1 – Design criteria and screening factors

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Chapter 6 System Rating Factors And Design Criteria

Rating factors form an integral part of the proposed preliminary selection tool. These factors are a means of numerically indicating how well an HVAC system is suited to fulfil the different design criteria. In this chapter, rating factors and the necessary correlation equations are presented for 16 generic HVAC system types. These factors were obtained by using historic and published data as well the expertise from various designers. The methods used can however be applied to rate other systems or incorporate new design criteria.

NOMINCLATURE

A : Area (m^2)

AE : Annual expense (R)

C_p : Initial capital investment (R)

E : Annual energy costs (R)

F : Maximum allowable rating

L : Equipment service life (Number of years)

M_p : Annual maintenance costs (R)

N : Life cycle cost period (Number of years)

NPV : Net present value (R)

R_i : System rating factor for design criteria i

R_p : Present value of replacement costs (R)

O_p : Present value of any other HVAC costs (R)

Q : Cooling load (kW)

Q_Z : Cooling load per zone (kW)

W : System weight (kg)

X : Year in which equipment is to be replaced

i : Escalation rate

e : Average inflation rate

Subscripts

A : Available

C : Calculated

E : Energy

M : Maintenance

P : Present value

Z : Zone

6.1 INTRODUCTION

A simple yet effective preliminary HVAC selection tool can be obtained by combining the positive features of both numerical ranking methods and expert systems. An integral part of this tool is the use of system rating factors. These factors are a means of numerically indicating how well a HVAC system is suited to fulfil the different design criteria.

Design criteria can be divided into quantifiable, e.g. maximum allowable system size, and subjective properties, such as aesthetic limitations. Rating factors for quantifiable system characteristics can be obtained by estimating these properties using published literature such as catalogues, system manuals, textbooks and historical data. Rating factors are taken to be the estimated system characteristics normalised for use in the selection tool.

Subjective design criteria are rated using the method suggested by Scanlon [1]. This consists of assigning the maximum rating to the system that best fulfils the desired design goal. The remaining systems are then rated relative to this system. These factors may differ depending on personal experience and knowledge. It is likely that different people may rate the systems differently. An improved average rating factor is obtained by basing these ratings on input from various experts.

In this chapter, rating factors and the necessary correlation equations are presented for 16 generic HVAC system types. These systems were given a rating between 0 and 5 for different design goals and limitations. A rating of five indicates that the system is well suited for the particular design criterion. It should be noted that the ratings are based on typical system characteristics. It is therefore possible to obtain or manufacture a system that can fulfil the desired task successfully, even though it is given a poor rating.

6.2 PRELIMINARY DESIGN INPUT

Quantifiable system characteristics and certain limitations are influenced by climate, building size and required cooling load. Preliminary design input is therefore required before system performance ratings can be calculated, namely:

1. Proposed building floor area,
2. maximum space available for HVAC system,
3. estimated cooling load requirements,
4. dry or humid climate, and
5. number of zones.

Floor area and cooling load are typically used as independent variables in calculating quantifiable factors. Estimating system cost based on floor area or cooling loads is a typical example of this. Climate and number of zones on the other hand serve as additional limitations in selecting a system.

Most of these factors are already known or established during the initial project meeting. A rough estimate of the cooling load requirements must however be made. This can easily be obtained by using a simplified load calculation tool. Such a tool was proposed and developed in Chapter 2. The calculated cooling load requirement is increased by 25% for full fresh air systems. This is done in order to take the extra outdoor air load into consideration. It will however vary depending on the climate and must be adjusted accordingly.

6.3 DESIGN CRITERIA

Typical design criteria used as basis for choosing a system are given in Table 5.1 in Chapter 5. Sixteen generic system types were evaluated according to how well they suit these requirements. Correlation equations for quantifiable design criteria were obtained, as well as ranking factors for subjective criteria. These rating factors are provided in Table 6.2. These criteria are discussed in more detail in the following paragraphs.

6.4 BUILDING RESTRICTIONS

6.4.1 Available space for the system

HVAC systems require a certain amount of floor space. This is divided into floor area required for the refrigerant plant and air-handling units, as well as the ceiling void and shaft spaces for piping and ducting. In existing buildings this can be a crucial element that restricts the use of certain system types. Although not as critical, these space requirements must also be taken into consideration during the design of new buildings. In some cases a compromise must be made due to other more important design criteria.

Floor area (A1)

Central systems and packaged rooftop units require a certain amount of floor space. Window, console and split units also require space but to a smaller extent. In most cases this is negligible. The outdoor units of larger split units can however be substantial. Window and console units are therefore given a rating of five. The remaining systems are rated accordingly.

Space required is dependent on the load requirements of the system. It stands to reason that the rating factor for this criterion also be dependent on the expected cooling load. Using catalogue data, a relation between floor space and cooling load was obtained for various systems. Figures 6.1 to 6.6 presents the different relations. These relations do not include ducting, piping and additional space needed for maintenance or airflow around equipment.

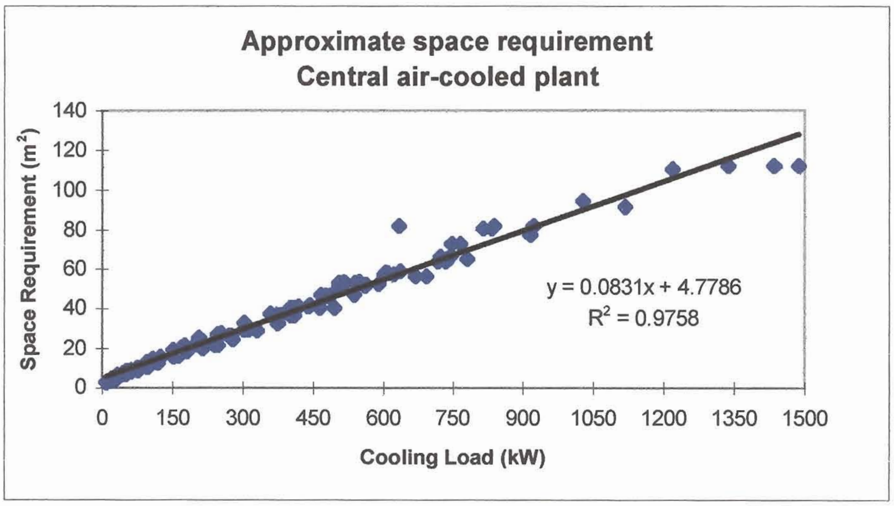

Figure 6.1 - Space requirement correlation for air-cooled all-air systems.

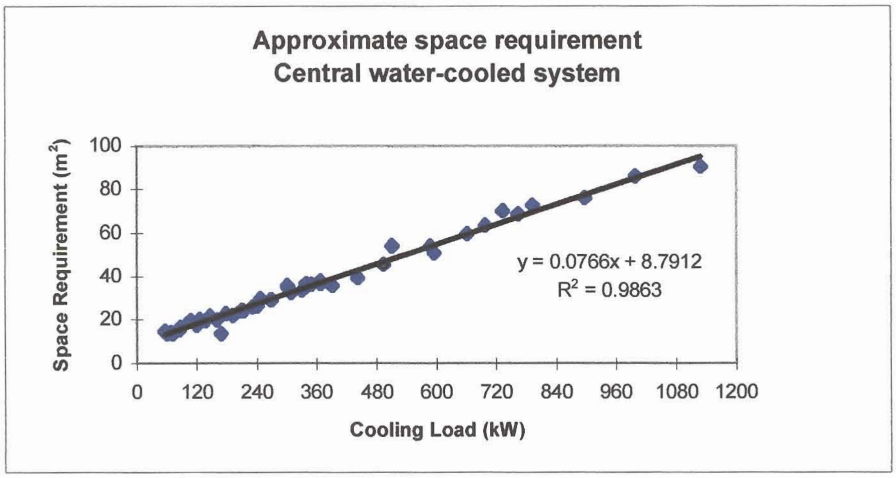

Figure 6.2 - Space requirement correlation for water-cooled all-air systems

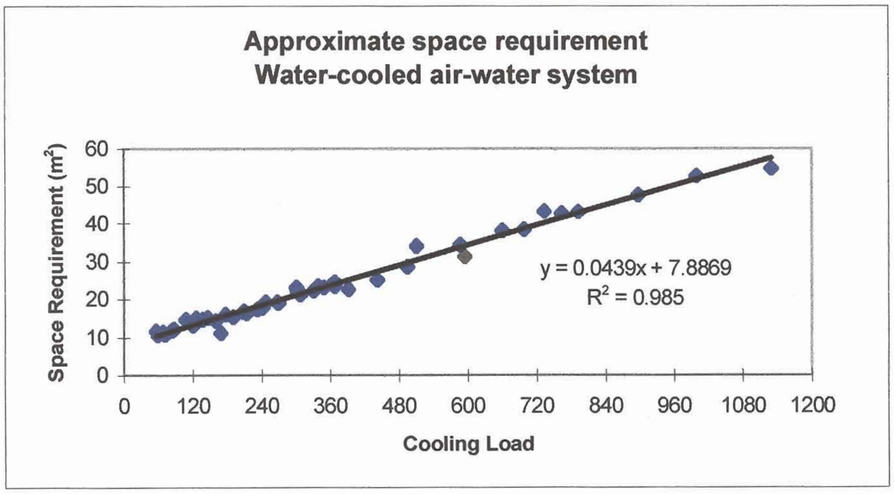

Figure 6.3 - Space requirement correlation for water-cooled air-water systems

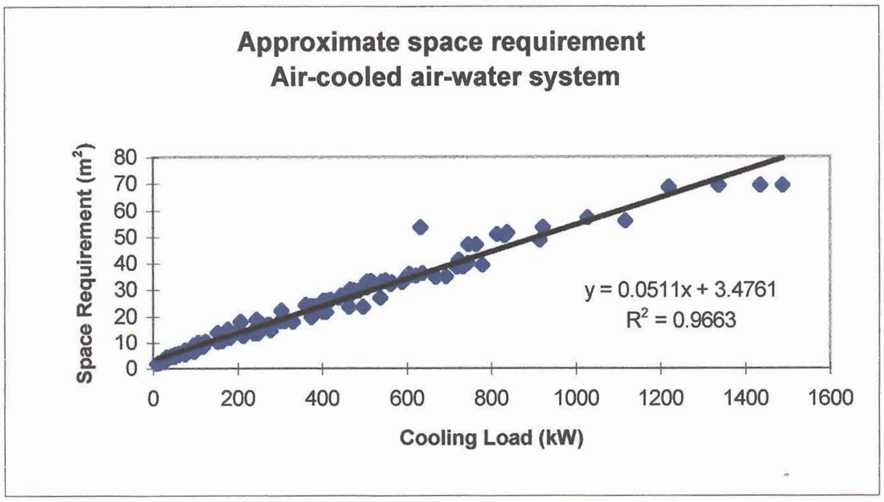

Figure 6.4 - Space requirement correlation for air-cooled air-water systems

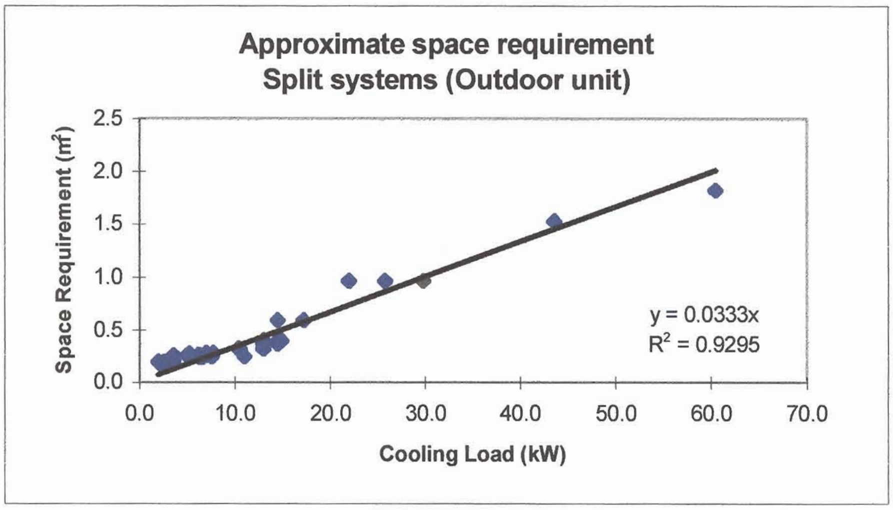

Figure 6.5 - Space requirement correlation for split systems

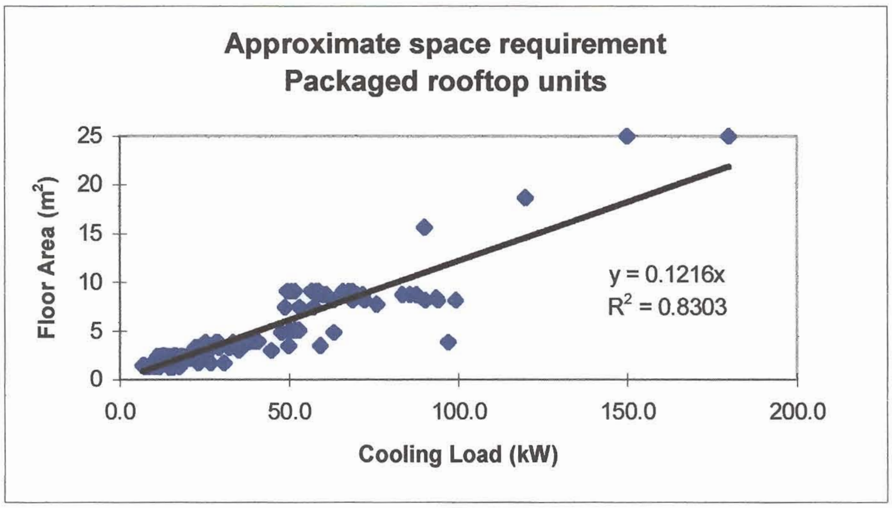

Figure 6.6 - Space requirement correlation for rooftop packaged units

Using these relations, an estimated area requirement for each system can be calculated. If the estimated area is smaller than the desired maximum, the system is given a rating of five. Otherwise it is rated depending on how much it exceeds the desired area. The rating factor is then calculated as follows:

$$R_i = F - \frac{(A_C - A_A)}{(A_C)} \times F \qquad (6.1)$$

Ceiling void and shaft space requirements (A2)

Central systems require ceiling void space and vertical shafts for ducting and piping. The use of all-air and some air-water systems can therefore be eliminated due to lack of sufficient space. Damhuis [2] and Chadderton [3] give a comparison of the relevant space requirements for different systems. The systems were rated using this information as basis. Water is approximately four times more efficient in transferring heating or cooling than air. Water systems therefore require less space to transfer the same amount of energy. Space required by mixed systems will vary depending on the ratio of cooling done by the primary air to that of the secondary water. This ratio was taken to be 1:1 for rating purposes.

Window and console units do not require space for ducting or piping. These systems are therefore given the maximum allowable rating. Rooftop package units usually supply air via a ducting system. Their rating is therefore the same as central all-air systems. Split systems require refrigerant pipes. They are however usually relatively small and not very long. These systems are consequently given a rating of four. Ducted-split systems are not considered here. Ducted-split system ratings must be determined in the same manner as all-air systems.

6.4.2 System mass (A3)

The mass of the system influences the structural requirements of a building. The more a system weighs, the stronger the building structure needs to be. System mass consequently directly influences the construction cost of a new building. In existing buildings, the system choice is furthermore restricted to the maximum carrying strength allowable for the structure. In both cases it is therefore preferable to keep the mass down as low as possible.

Items located on the roof of a building have the highest structural impact. Equipment such as cooling towers, packaged rooftop units, and air-cooled refrigeration machines are frequently located on the roof. Relations for mass to cooling load were obtained for these equipment types. Systems using this equipment were rated accordingly, and the rest are given a rating of five by default.

A rating factor for this criterion is obtained by normalising the estimated system mass relative to the system with the maximum mass.

$$R_i = F - \frac{(Estimated\ System\ Mass)}{(Maximum\ Mass)} \times F \qquad (6.2)$$

These factors are however only taken into consideration if equipment needs to be installed on the roof.

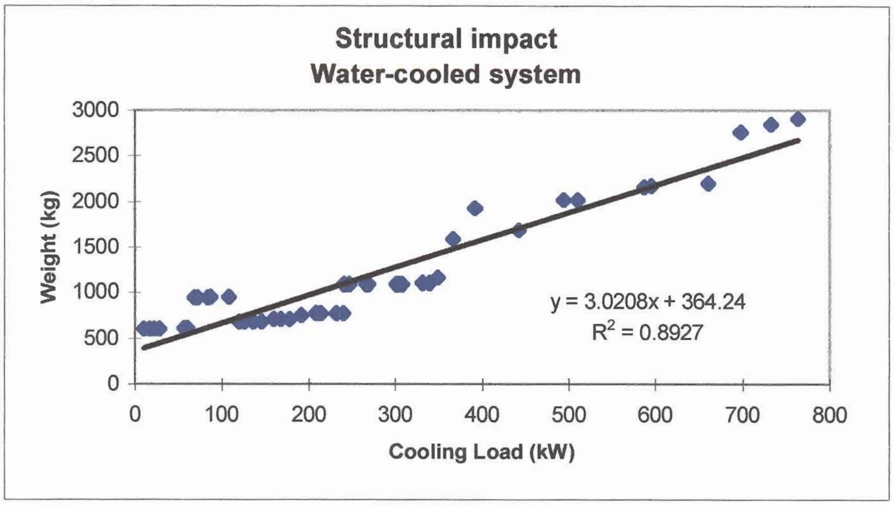

Figure 6.7 - Mass correlation for water-cooled system cooling towers

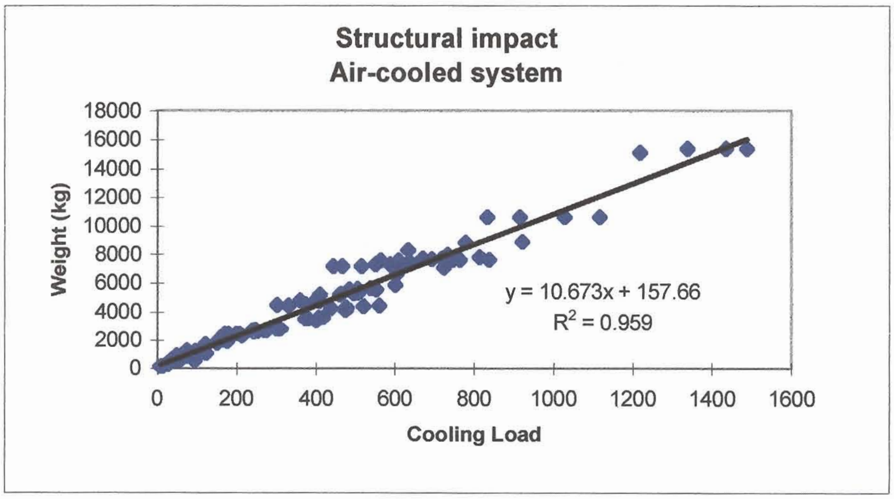

Figure 6.8 – Mass correlation for air-cooled refrigeration machine

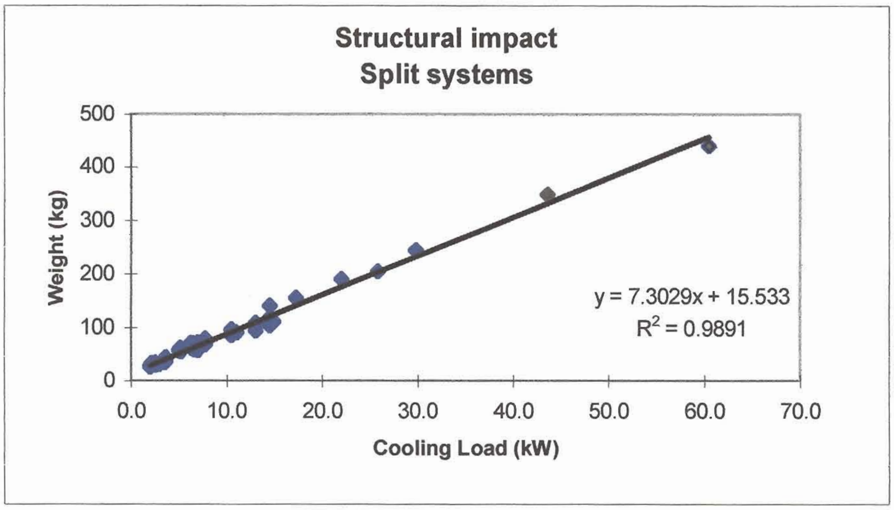

Figure 6.9 - Mass correlation for the outdoor unit of a split system

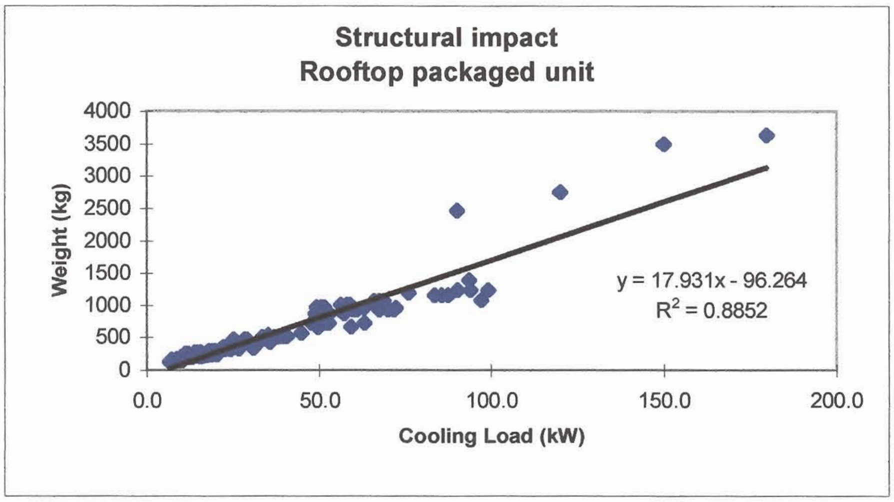

Figure 6.10 – Mass correlation for rooftop packaged units

6.4.3 Zoning (A4)

Some systems can only be used in perimeter zones. Typical examples are window and console units. These systems are given a rating of nought. Most of the other systems can however be adjusted to cope with interior zones. Split systems and air-water systems however will potentially need drainage facilities for condensate. These systems are therefore less suited to interior zones unless located near a drainage point.

6.5 AESTHETIC LIMITATIONS

Air-conditioning systems influence the overall aesthetics of a building. In general it is preferable to hide the system as much as possible. Modern window, console, and split units are colour coded to blend into the surroundings. Larger central systems are usually located in a separate plantroom or enclosure. Inlet and exhaust grilles for ventilation are other features of the HVAC system that must be considered in the building design.

6.5.1 Indoor equipment (B1)

In some cases it is aesthetically undesirable to have equipment located within a zone. Constant volume all-air systems and packaged rooftop units only require supply and return air diffusers within the zone. Variable volume systems further require either a mixing box or additional zone fan. Air-water systems and split systems have a fan and cooling coil combination within the zone. The entire system of window and console units are located within the zone.

6.5.2 Window units (B2)

Window units are probably the most visible system from the outside and inside. These systems are also prone to condensate drip. They are consequently generally, aesthetically speaking, unacceptable in most cases. These systems are however relatively cheap and easy to install. In some cases their usage is further restricted due to the overall building construction. A typical example is a building with a full glass facade.

6.5.3 Grilles and condensers (B3)

Console or through-the-wall units require an outside grille for each installed unit. The outdoor units of split systems require a ledge or they must be wall mounted to the outside of the building. These units can also be located on the roof or ground for low-rise buildings. These features must be incorporated in the design of the building.

6.5.4 Rooftop and exterior enclosures (B4)

Air-cooled refrigerant plants, cooling towers, rooftop-packaged units and the outdoor units of split systems need to be aesthetically concealed. This is usually done by building an enclosure to house the equipment. The volume taken up by these systems largely influences the ease with which the system can be concealed. Ratings for the different systems are obtained in a similar fashion as the structural impact factors.

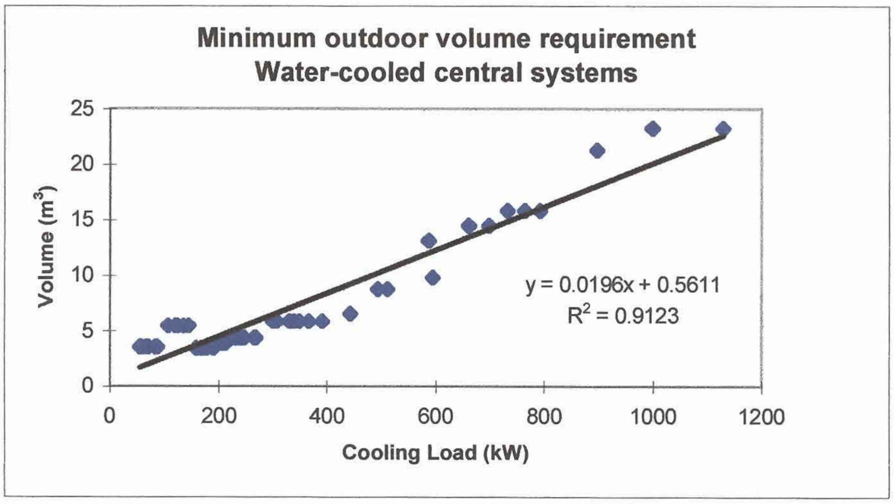

Figure 6.11 - Outdoor volume correlation for water-cooled system cooling towers

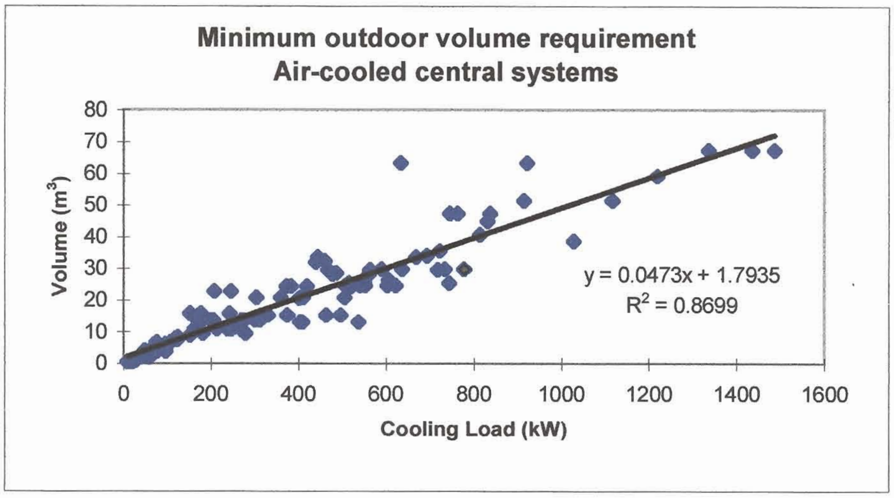

Figure 6.12 - Outdoor volume correlation for air-cooled refrigeration machines

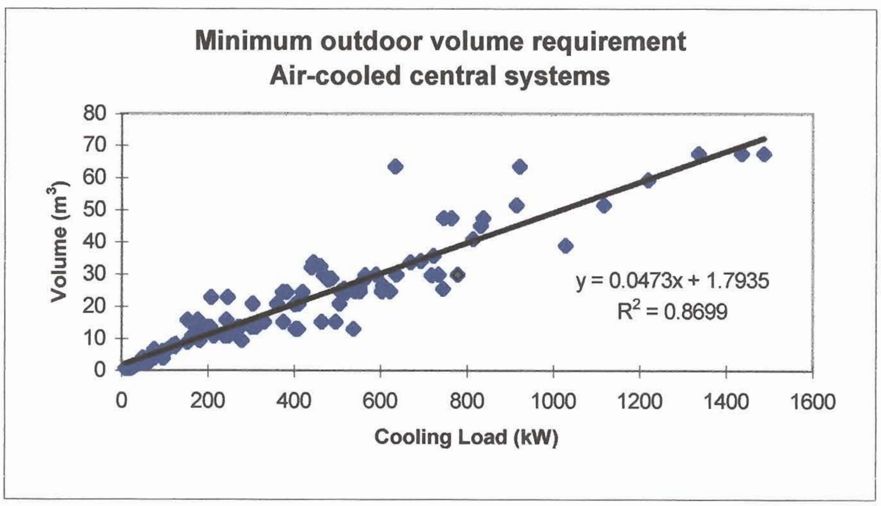

Figure 6.13 - Outdoor volume correlation for rooftop packaged unit

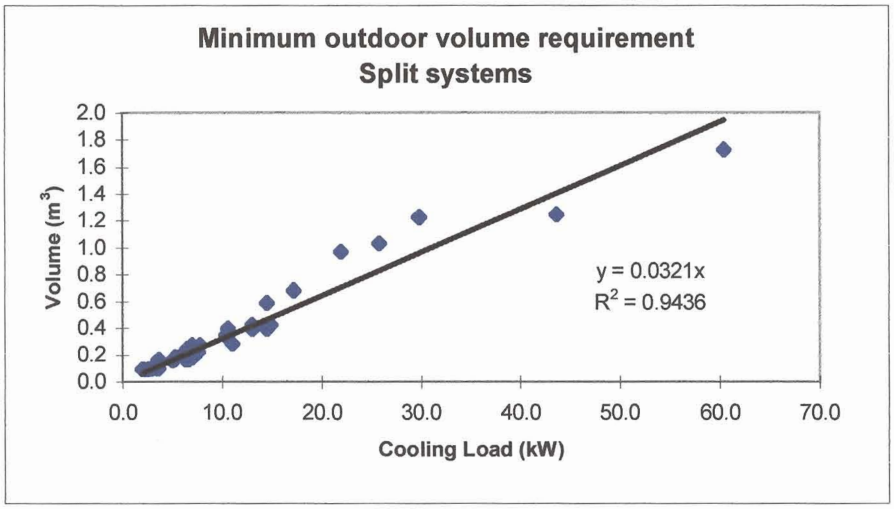

Figure 6.14 - Outdoor volume correlation for split system outdoor unit

6.6 SYSTEM REQUIREMENTS

6.6.1 Indoor noise (C1)

HVAC equipment generates noise. Central systems are however well suited to reduce the noise within the building. The major noise generating equipment such as compressors and fans are far away from the building. These system types also have a wide range of vibration and noise damping equipment available. Equipment located within the zone on the other hand tends to be noisy. Split systems benefits from the fact that the systems compressors are located outside of the building.

6.6.2 Skilled system operators (C2)

Central systems require a skilled systems operator to monitor and run the equipment efficiently. A typical example being two-pipe systems that need to be manually adjusted from summer to winter conditions. Packaged and unitary room equipment on the other hand is simple to operate and maintain as they are built from standard equipment. Most people can operate them. They are frequently referred to as appliances.

6.6.3 In-zone maintenance (C3)

Air-conditioning systems needs maintenance to ensure that they remain operational. This can cause disruptions if the equipment is located in occupied areas. This is especially true for the unitary type systems located completely within the occupied areas. The more prominent equipment of central systems that requires frequent service is located away from occupied areas. Variable volume systems and air-water systems do however have mixing boxes, fans and filters which are located within the building and sometimes occupied spaces.

6.6.4 Individual control (C4)

Different people have different comfort requirements. In order to satisfy everyone the system needs individual control settings for each of the occupants. Unitary window, console and split systems are ideal for this. Central systems on the other hand are usually regulated according to a single design setting. Most air-water systems do allow, to a certain extent, individual adjustment of each fan-coil or induction unit. Some variable volume systems also allow individual control of the VAV mixing boxes.

6.6.5 Load diversity (C5)

Zones on opposite sides of a building can have a huge variance in the load requirements. In some cases it can be that one zone requires cooling while another needs heating. Two pipe systems that requires a manual switch over from refrigerant plant to boiler will thus be unable to cope with this load diversity. It is however possible to cope with this diversity by equipping each zone with a separate heating system. Most systems will be able to cope with load diversity if separate zones have their own air-handling units and heating system. Multi-zoned systems were not taken into consideration.

6.7 AIR QUALITY AND FLOW RESTRICTION

The quality and requirements of airflow play an integral part in selecting an appropriate air-conditioning system. These requirements are often dictated by special processes or equipment located in the building.

6.7.1 Filtration (D1)

In dusty areas or clean-room applications it is essential that the air be filtered sufficiently. Typical applications where filtration is essential are operating theatres and mainframe computer or electronic control rooms. Central all-air systems are particular well suited for this. There is a wide range of high quality and durable filtration equipment available for these systems. Air-water systems can use the same filtration equipment as all-air systems. Only the primary air supply however is filtered. Packaged units are also usually fitted with substantial air filters, but these systems are restricted to standardised equipment. Window, console and split systems on the other hand, are generally only supplied with lint screens to protect their cooling coils from dust build-up.

6.7.2 Air contamination (D2)

Mixing of air from different building zones can sometimes be undesirable. This is especially true if the zones under consideration are full of volatile contaminants. Hospital wards or chemical laboratories are typical examples of such zones. These zones require systems that supply sufficient outdoor air to flush out the contaminants. Window, console and split units usually do not make provision for outdoor air supply. These systems are therefore generally unsuitable for these applications.

6.7.3 Room pressurisation (D3)

Some buildings require specialised make-up air in order to keep zones under positive pressure. This is usually necessary to ensure that surrounding air does not infiltrate the zone. A typical application is to keep smoke out of certain areas in the event of a fire. Systems required for this need to be able to supply more air than is being extracted. These systems consequently need substantial ventilation capabilities.

6.7.4 Outdoor air supply (D4)

One of the main functions of HVAC equipment is to supply adequate amounts of outdoor air. In most cases this is a legal requirement. ASHRAE standard 62-1989 [4] gives the typical minimum requirements for different types of buildings. Window, console and most split units do not make provision for supplying any outdoor air. These systems thus require additional provision for supplying outdoor air to the zone.

6.7.5 Humidity (D5)

Indoor humidity is one of the comfort indices often overlooked. In some cases it is essential to maintain the relative humidity levels within certain margins. Static electricity can cause major damage in electronic control and computer rooms. Humidity control can easily be incorporated in large central systems. These systems are however usually absent in smaller room equipment. Certain split systems designed for computer room applications do however make provision for humidity control.

6.8 BUILDING MANAGEMENT REQUIREMENTS

6.8.1 Central building management system (E1)

From an energy savings and system managing perspective it is ideal to regulate the system from one control station. Building Management Systems (BMS) provides this control. These systems can easily be incorporated into the control of central systems. Window units, console units and spilt systems are usually not suited for this type of control system. Rooftop package units are usually furnished with their own standardised control system. These systems do not always make provision for interfacing with a building management system.

6.8.2 Unused zones (E2)

It is desirable to be able to switch of the air-conditioning in zones not being used. This saves energy and money that would otherwise be wasted. Typical applications are hotels and buildings that are only partially used. Window units, console units and split systems are ideal for this as they can be individually operated. Air-water systems also partially fulfil this requirement by allowing the individual fan-coil or induction units to be switched off. The primary air and cooling plant will however still be operational.

6.8.3 Separate billing (E3)

In multi-tenant buildings it is often necessary to measure the air-conditioning energy consumption of each tenant separately for billing purposes. The ideal would be that each area leased by the tenant has its own air-conditioning system. Unitary window units, console units or split systems are ideal for this. These systems are however impractical for bigger buildings.

Air-water system can also be metered to a certain extent. Conditioned water and fan power consumption can be measured for each fan-coil or induction unit used by the tenant. The primary air usage is generally constant and can be billed according to a flat rate. This can however not be done for all-air systems, as it is difficult to measure how much each patron adds to the total building load.

6.8.4 Flexibility (E4)

Buildings are dynamic commodities. Their requirements and interior layout may change over their life cycle. System flexibility is an indication of how well the system can be adapted to provide the same function with a different configuration. This is typically required in buildings where the interior layout frequently changes. Buildings where office space is often adapted to meet various tenants requirements is an example of this. In America, approximately 25 percent of the people employed in the commercial sector are relocated each year [5].

Systems that do not require major structural change are ideal for buildings with a high turnover. All-air systems designed in close co-operation with the architect can fulfil this need. In most cases the return and supply outlets need only be moved. Window and console units on the other hand are built into the building façade and are consequently costly to move.

6.9 SYSTEM COST

The cost of installing and operating the system is, and probably always will be, one of the most important factors in selecting a system. A project will not be completed without the necessary capital funding. The financial implication of system selection varies depending on the owner's goals. Developers are generally more interested in systems with a low initial cost. Building owners will also take into consideration the operating and maintenance cost of the system over a period of time. Life-cycle cost analysis is therefore required.

Buys [6] gives a short overview of simple life-cycle costing techniques used in the building industry. The net present value method is frequently used since it is simple yet applicable for medium to long term analysis. This method consists of calculating the present value of all the relevant cash flows for a certain period of time.

$$NPV = C_p + E_p + M_p + R_p + O_p \tag{6.3}$$

The time period used to do the financial analysis strongly influences the system choice. Shorter periods will favour systems with a lower initial cost. Longer periods will however favour systems with low operating and maintenance cost. The initial cost is used for the short-term analysis period. Ten and twenty years were respectively used for medium- and long term cost analysis.

Energy (E) and maintenance (M) are annual operating expenses. The cost of energy and maintenance however increases over time as the system deteriorates. Expressing this increase as an annual escalation rate, the net present value of these expenses can be calculated using standard economic cash flow relationships [7].

$$P = AE\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right]. \qquad (6.4)$$

where AE is the constant annual expense if no cost increase occurred.

The value of money furthermore decreases with time due to inflation. By taking inflation into account equation 6.4 becomes

$$P = AE\left(\frac{1+e}{i-e}\right)\left[1-\left(\frac{1+e}{1+i}\right)^N\right]. \qquad (6.5)$$

with e being the average inflation rate for the analysis period.

The service life of HVAC equipment must also be taken into consideration in the economic analysis. Typical service lives for various system components can be found in ASHRAE [8]. Certain equipment may need to be replaced during the analysis period. The replacement cost of this equipment can be calculated using the present cost of equipment corrected for inflation.

$$R_P = C_P(1+e)^L \qquad (6.6)$$

Assuming that there are no other expenses, equation 6.3 becomes:

$$NPV = C_P + E\left(\frac{1+e}{i_E - e}\right)\left[1-\left(\frac{1+e}{1+i_E}\right)^N\right] + M_p\left(\frac{1+e}{i_M - e}\right)\left[1-\left(\frac{1+e}{1+i_M}\right)^N\right] + C_P(1+e)^L \qquad (6.7)$$

The capital cost (C_P) of the systems can be estimated using historical data. Data gathered by Konkel [9] and suppliers were used for this purpose. Some of the data is based on American labour rates. This data can however be applied since it is only used to compare equipment relative to one another. All costs are converted to South African currency with 1993 as cost basis.

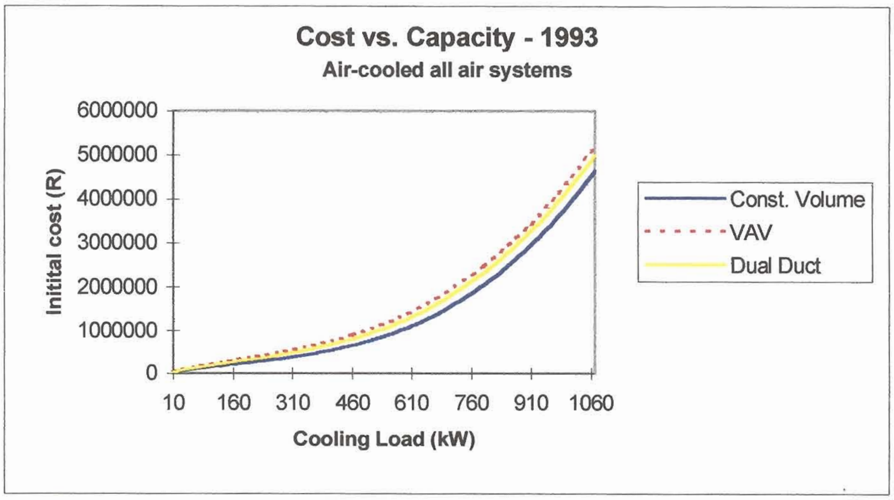

Figure 6.15 - Cost versus capacity relation for air-cooled all-air systems

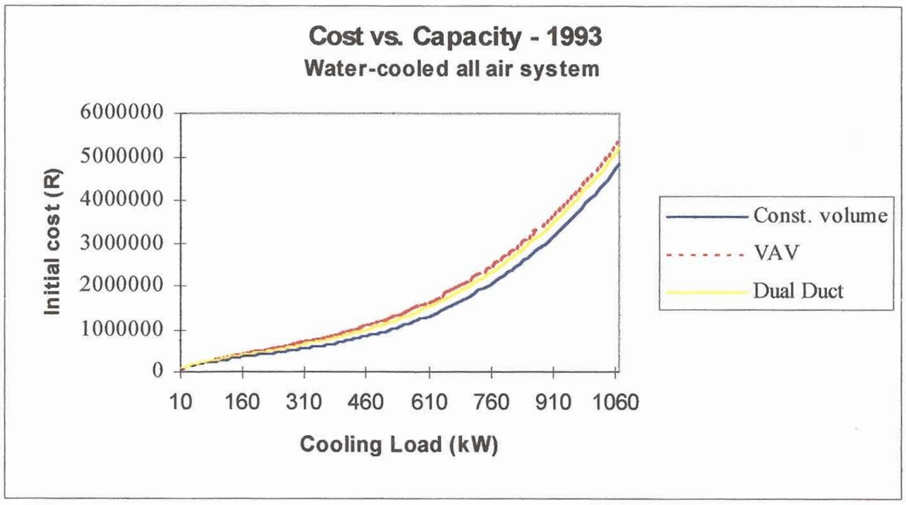

Figure 6.16 - Cost versus capacity relation for water-cooled all-air systems

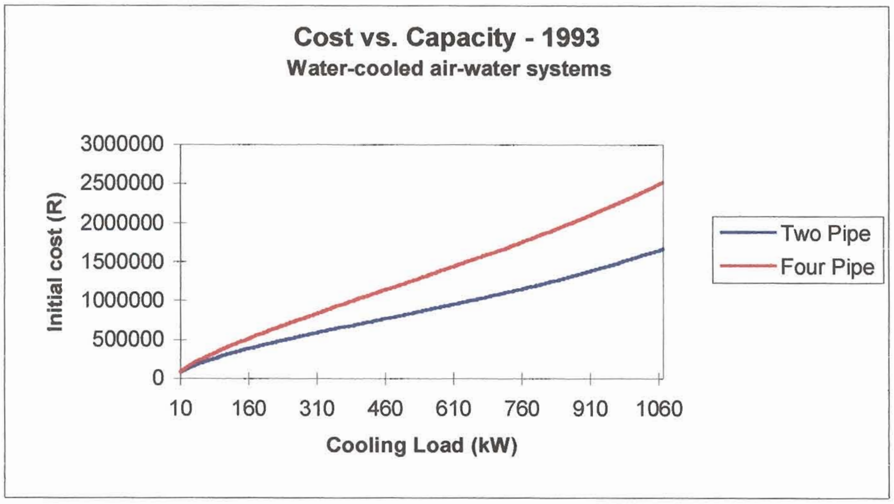

Figure 6.17 - Cost versus capacity relation for water-cooled air-water systems

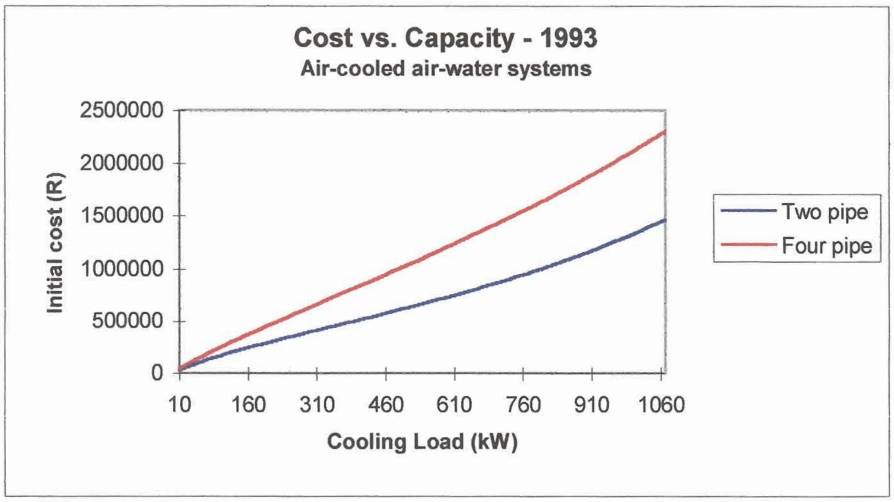

Figure 6.18 - Cost versus capacity relation for air-cooled air-water systems

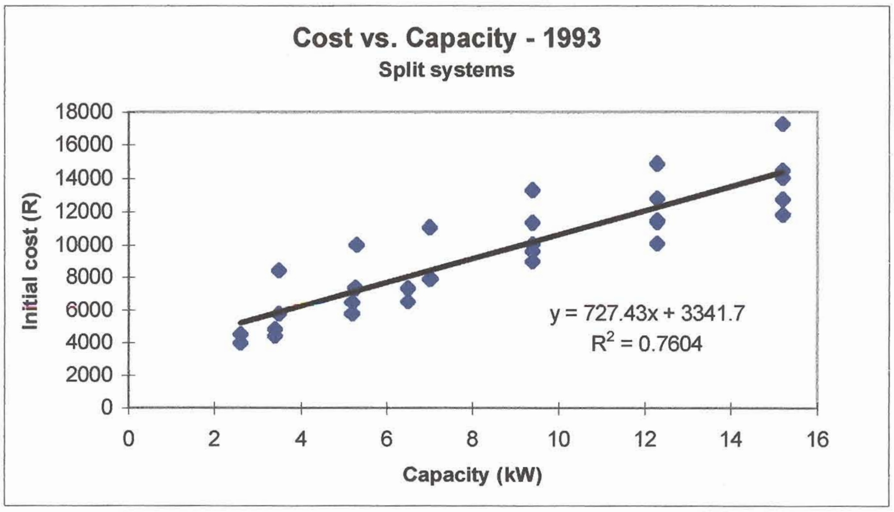

Figure 6.19 - Cost versus capacity relation for split systems

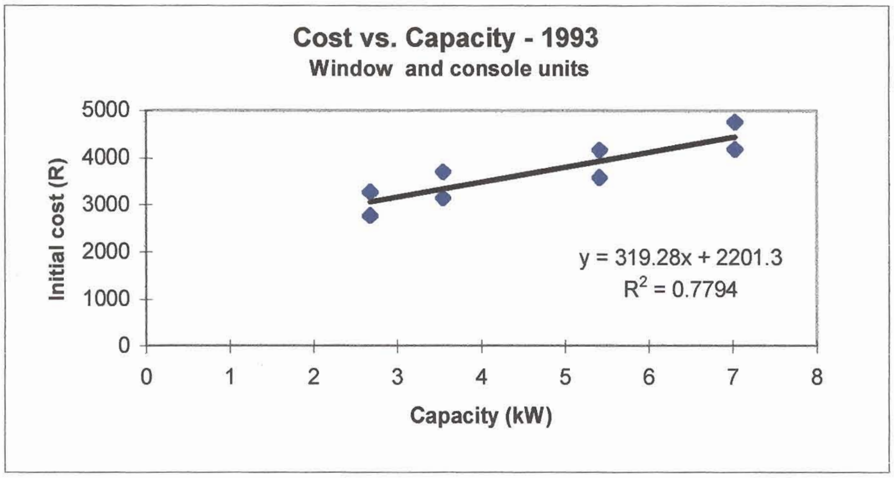

Figure 6.20 - Cost versus capacity relation for window and console units

In general, South African consultants and contractors estimate yearly maintenance cost as a percentage of the replacement value of the system [6]. This percentage varies depending on the installed system. Typical values are given in Table 6.1. Maintenance cost will increase as the system deteriorates. This increase is taken into consideration with a maintenance escalation rate.

Obtaining the energy expense of the various systems is not a simple task. It is a function of the energy tariff structure, building characteristics and climate. A simplified characteristic value can however be obtained using cost data from existing buildings. Alternatively, a cost database can be created using integrated simulation software.

Using a simulation tool, the annual energy consumption of various systems can be calculated for a particular building [10]. By applying an average energy tariff, the annual cost can be estimated for each of the system types. Using this database a simple annual cost per square meter value can be obtained. Illustrative values are given in Table 6.1. Energy consumption will increase as the system ages. This is due to a decrease in the energy efficiency of worn equipment. This is taken into consideration by using an energy escalation rate.

System ratings based on estimated cost are obtained by normalising the system cost relative to the system with the highest cost.

$$R_i = F\frac{(NPV_i - NPV_{min})}{(NPV_{max} - NPV_{min})} \times F \qquad (6.8)$$

It must be stressed that this cost estimation is not very accurate due to the multiple assumptions made. The estimates will however provide reasonable values that can be used to quickly compare the various systems to each other. A sensitivity analysis can be performed in more critical situations by changing the cost ratios and noting what the influence is on the system ranking.

6.10 PRELIMINARY DESIGN RESTRICTIONS

6.10.1 Cooling capacity (G1)

The required cooling capacity also influences the selection of a system. It is impractical to select a system type with a maximum capacity lower than required. The opposite also applies. According to the numerous catalogues and brochures studied, the following typical characteristic capacity ranges were identified:

- Water-cooled central systems $Q > 30$ kW
- Air-cooled central systems $Q > 10$ kW
- Split systems $Q < 60$ kW (per zone)
- DX unitary systems $Q < 10$ kW (per zone)
- Rooftop packaged units $7 < Q < 180$ kW

These capacity ranges may however vary in different countries.

Systems are given a rating of one if the cooling capacity falls within the typical capacity range. If not, they are given a rating of zero. Total cooling capacity is used to check central systems. Unitary and split system compliance is checked using the capacity per zone requirements. For the purposes of the preliminary selection tool the capacity per zone is estimated as total cooling capacity divided by the number of zones.

6.10.2 Climate (G2)

Water-cooled systems use mass transfer of water vapour and heat transfer as a means of rejecting heat to the surrounding atmosphere. In a hot dry climate, evaporation takes place easily. In humid climates however this is less effective. Air-cooled systems are given a rating of five, and water-cooled zero. These factors are however only taken into consideration if the user indicates that the system is located in a humid climate.

6.11 SUMMARY

Typical design criteria used for selecting systems were identified and discussed. Rating factors and correlation equations were obtained for these criteria. Correlation equations are summarised in Table 6.1. Using these relations, rating factors can be obtained by normalising each system characteristic relative to the system with the worst characteristic.

The correlation equations for full fresh air and economiser systems are the same. The only difference being that the system load requirements must be increased to cope with the increased outdoor load. In this selection tool it was done by increasing the load by 25%.

Subjective design criteria are rated based on experience and expert knowledge. To reduce prejudice towards certain systems, it is preferable that the expertise from various designers be used in rating the systems. Typical rating factors are given in Table 6.2.

Air-conditioning system	Initial Cost C_P =	Maintenance Cost % of C_P	Energy Cost R/m²/year	Area (m²) A =	Structural Impact (kg) W =	Volume V =
1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	$0.0047(1.25Q)^3 - 2.766(1.25Q)^2 + 1876.2(1.25Q) + 88266$	2.5%	12.2	0.0766(1.25Q) + 8.7912	3.0208(1.25Q) + 364.24	0.0196(1.25Q) + 0.5611
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	$0.0044(1.25Q)^3 - 1.9291(1.25Q)^2 + 1319.5(1.25Q) + 24661$	2.5%	14.8	0.0831(1.25Q) + 4.7786	10.673(1.25Q) + 157.66	0.0473(1.25Q) + 1.7935
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	$0.0047Q^3 - 2.766Q^2 + 1876.2Q + 88266$	2.5%	10.4	0.0766Q + 8.7912	3.0208Q + 364.24	0.0196Q + 0.5611
4. All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	$0.0044Q^3 - 1.9291Q^2 + 1319.5Q + 24661$	2.5%	12.2	0.0831Q + 4.7786	10.673Q + 157.66	0.0473Q + 1.7935
5. All-air, dual duct system with water-cooled refrigeration plant.	$0.0046Q^3 - 2.4623Q^2 + 2145.8Q + 90684$	3.0%	9.7	0.0766Q + 8.7912	3.0208Q + 364.24	0.0196Q + 0.5611
6. All-air, dual duct system with air-cooled refrigeration plant.	$0.0043Q^3 - 1.7322Q^2 + 1591Q + 27140$	3.0%	11.8	0.0831Q + 4.7786	10.673Q + 157.66	0.0473Q + 1.7935
7. All-air, variable volume, economiser system and water-cooled refrigeration plant.	$0.0047Q^3 - 2.6828Q^2 + 2433.8Q + 88236$	3.0%	11.8	0.0766Q + 8.7912	3.0208Q + 364.24	0.0196Q + 0.5611
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.	$0.0044Q^3 - 1.9553Q^2 + 1880.4Q + 24702$	3.0%	9.5	0.0831Q + 4.7786	10.673Q + 157.66	0.0473Q + 1.7935
9. Four-pipe system with air-cooled refrigeration plant.	$2053.7Q + 19327$	3.0%	10.2	0.0511Q + 3.4761	10.673Q + 157.66	0.0473Q + 1.7935
10. Four-pipe system with water-cooled refrigeration plant.	$2155.2Q + 144616$	3.0%	12.7	0.0439Q + 7.8869	3.0208Q + 364.24	0.0196Q + 0.5611
11. Two-pipe system with air-cooled refrigeration plant.	$0.0007Q^3 - 0.8623Q^2 + 1435.2Q + 30493$	3.0%	9.7	0.0511Q+ 3.4761	10.673Q + 157.66	0.0473Q + 1.7935
12. Two-pipe system with water-cooled refrigeration plant.	$0.001Q^3 - 1.5853Q^2 + 1988.6Q + 94133$	3.0%	12.2	0.0439Q + 7.8869	3.0208Q + 364.24	0.0196Q + 0.5611
13. Split systems	$727.43Q + 3341.7$	2.8%	14.4	0.0333Q	7.3029Q + 15.533	0.0321Q
14. Window units	$319.28Q + 2201.3$	3.3%	14.4	Negligible	Negligible	Negligible
15. Through-the-wall console units	$319.28Q + 2201.3$	3.3%	14.4	Negligible	Negligible	Negligible
16. Packaged rooftop units	$603.76Q + 9505.9$	3.3%	11.6	0.1216Q	17.931Q - 96.264	0.241Q - 2.9694

Table 6.1 - Summary of system correlations equations and data.

Air-conditioning system	Building Restrictions				Aesthetic Limitations				System Requirements				
	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	C5
1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	Calculate	2	Calculate	5	5	5	5	Calculated	5	0	4	0	1
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	Calculate	2	Calculate	5	5	5	5	Calculated	5	1	5	0	1
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	Calculate	1.5	Calculate	5	5	5	5	Calculated	5	0	4	0	1
4. All-air, variable air temperature, economiser system and air- cooled refrigeration plant.	Calculate	1.5	Calculate	5	5	5	5	Calculated	5	1	5	0	1
5. All-air, dual duct system with water-cooled refrigeration plant.	Calculate	0	Calculate	5	4	5	5	Calculated	5	0	3	1	2
6. All-air, dual duct system with air-cooled refrigeration plant.	Calculate	0	Calculate	5	4	5	5	Calculated	5	0	4	1	2
7. All-air, variable volume, economiser system and water- cooled refrigeration plant.	Calculate	1	Calculate	5	3	5	5	Calculated	4	0	4	2	2
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.	Calculate	1	Calculate	5	3	5	5	Calculated	4	0	4	2	2
9. Four-pipe system with air-cooled refrigeration plant.	Calculate	3	Calculate	4	2	5	5	Calculated	3	0	3	3	3
10. Four-pipe system with water-cooled refrigeration plant.	Calculate	3	Calculate	4	2	5	5	Calculated	3	0	3	3	3
11. Two-pipe system with air-cooled refrigeration plant.	Calculate	4	Calculate	4	2	5	5	Calculated	3	0	3	3	1
12. Two-pipe system with water-cooled refrigeration plant.	Calculate	4	Calculate	4	2	5	5	Calculated	3	0	2	3	1
13. Split systems	Calculate	4	Calculate	3	1	5	2.5	Calculated	3	4	3	4	4
14. Window units	5	5	5	0	0	0	0	Calculated	0	5	0	5	5
15. Through-the-wall console units	5	5	5	0	0	5	0	Calculated	0	5	0	5	5
16. Packaged rooftop units	Calculate	1.5	Calculate	5	5	5	5	Calculated	5	3	5	0	1

Table 6.2 - System ranting values

Air-conditioning system	Air Quality and flow Restrictions					Building Management				Cost	Preliminary Design Restrictions	
	D1	D2	D3	D4	D5	E1	E2	E3	E4	F	G1	G2
1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	5	5	5	5	5	5	0	0	5	Calculate	Q>30 - 5 ; Else - 0	0
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	5	5	5	5	5	5	0	0	5	Calculate	Q>10 - 5; Else - 0	5
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	5	3	5	5	5	5	0	0	5	Calculate	Q>30 - 5 ; Else - 0	0
4. All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	5	3	5	5	5	5	0	0	5	Calculate	Q>10 - 5 ;Else - 0	5
5. All-air, dual duct system with water-cooled refrigeration plant.	5	3	5	5	5	5	0	0	0	Calculate	Q>30 - 5 ; Else - 0	0
6. All-air, dual duct system with air-cooled refrigeration plant.	5	3	5	5	5	5	0	0	0	Calculate	Q>10 - 5 ; Else - 0	5
7. All-air, variable volume, economiser system and water-cooled refrigeration plant.	5	2	5	4	5	5	0	1	4	Calculate	Q>30 - 5 ; Else - 0	0
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.	5	2	5	4	5	5	0	1	3	Calculate	Q>10 - 5 ; Else - 0	5
9. Four-pipe system with air-cooled refrigeration plant.	3	2	3	3	3	3	3	3	2	Calculate	Q>10 - 5 ; Else - 0	5
10. Four-pipe system with water-cooled refrigeration plant.	3	2	3	3	3	3	3	3	2	Calculate	Q>30 - 5 ; Else - 0	0
11. Two-pipe system with air-cooled refrigeration plant.	3	2	3	3	3	2	3	3	3	Calculate	Q>10 - 5 ; Else - 0	5
12. Two-pipe system with water-cooled refrigeration plant.	3	2	3	3	3	2	3	3	3	Calculate	Q>30 - 5 ; Else - 0	0
13. Split systems	0	0	0	0	3	1	5	5	2	Calculate	Q_z<60 -5 ; Else - 0	5
14. Window units	0	0	0	0	0	0	5	5	0	Calculate	Q_z<60 -5 ; Else - 0	5
15. Through-the-wall console units	0	0	0	0	0	0	5	5	0	Calculate	Q_z<10 -5 ; Else - 0	5
16. Packaged rooftop units	3	3	4	5	4	3	0	0	4	Calculate	7<Q<180 - 5 ; Else - 0	5

Table 6.2 - System ranting values (Continued)

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Chapter 7 Application Of The Simplified Design Tools

The simplified design tools developed in the preceding chapters can greatly aid designers. They were applied to design a typical office building in order to demonstrate their use. Ninety-six different building configurations were analysed with the new thermal design tool. A cooling system was selected for the building with the best performance using the preliminary system selection tool.

7.1 INTRODUCTION

The simplified design tools developed in the preceding chapters can greatly aid designers. In order to demonstrate their use, they were applied to design a typical building. For the purpose of this demonstration it was assumed that the client requires an office building of approximately 2500m^2. The building is to be located in Pretoria. The thermal design tool was used to determine the effect that various architectural decisions have on the thermal efficiency of the building.

The analysis indicates that the difference in the cooling and heating system size requirements for the best and worst building configurations respectively are a 54% and 66%. An HVAC system was selected for one of the more efficient building designs. This selection was performed using the system rating factors and preliminary selection tool. The selection is based on typical criteria of a building developer that leases out office space. The building is further taken to be a medium term investment.

7.2 THERMAL ANALYSIS OF AN OFFICE BUILDING

The building used for this demonstration is to have a floor area of approximately 2500m^2. Building form, glazing area, orientation, and construction is however varied in order to determine its effect on the thermal characteristics of the building. A simulation matrix was set up similar to that of Batty [1] and Todesco [2]. Figure 7.1 gives a graphic representation of all the variables. The analysis consists of evaluating all ninety-six combinations of these variables.

The building requiring the smallest HVAC system is taken to be the best solution from a thermal efficiency perspective.

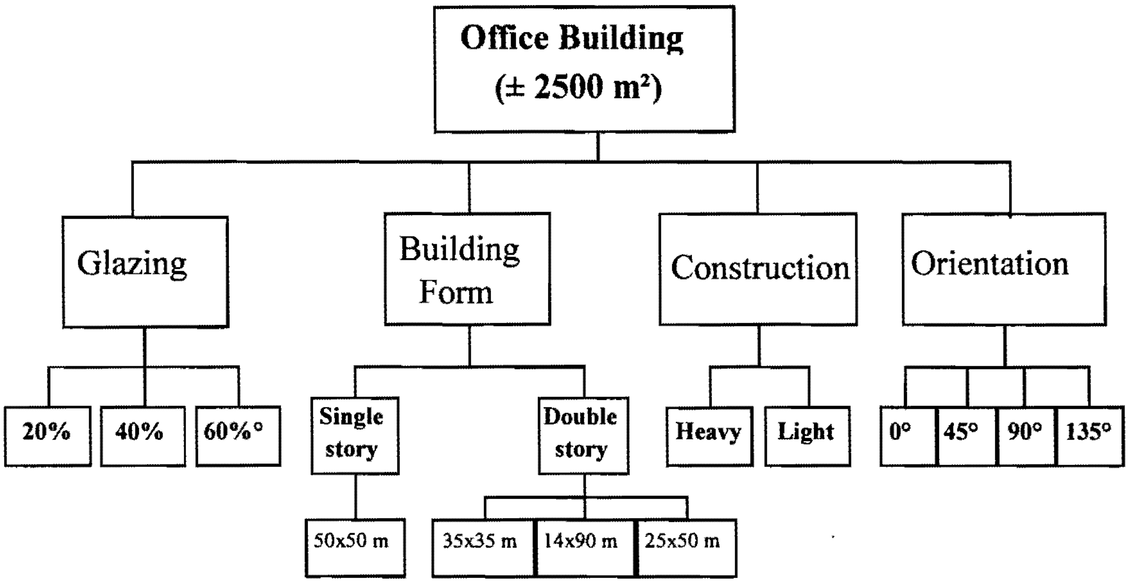


Figure 7.1 – Simulation variables used for the thermal analysis

7.3 ANALYSIS RESULTS

The analysis results are depicted in a series of surface graphs in Figures 7.2 and 7.3. The required cooling and heating system sizes are plotted as a function of building form and orientation. Building form is expressed by the building area exposed to the sun, as a proportion of the floor area.

Building orientation is the angle between true north and the perpendicular of a reference wall surface. For this analysis the reference wall was taken to be the wall with the dominant surface area. The angle is measured clockwise from north.

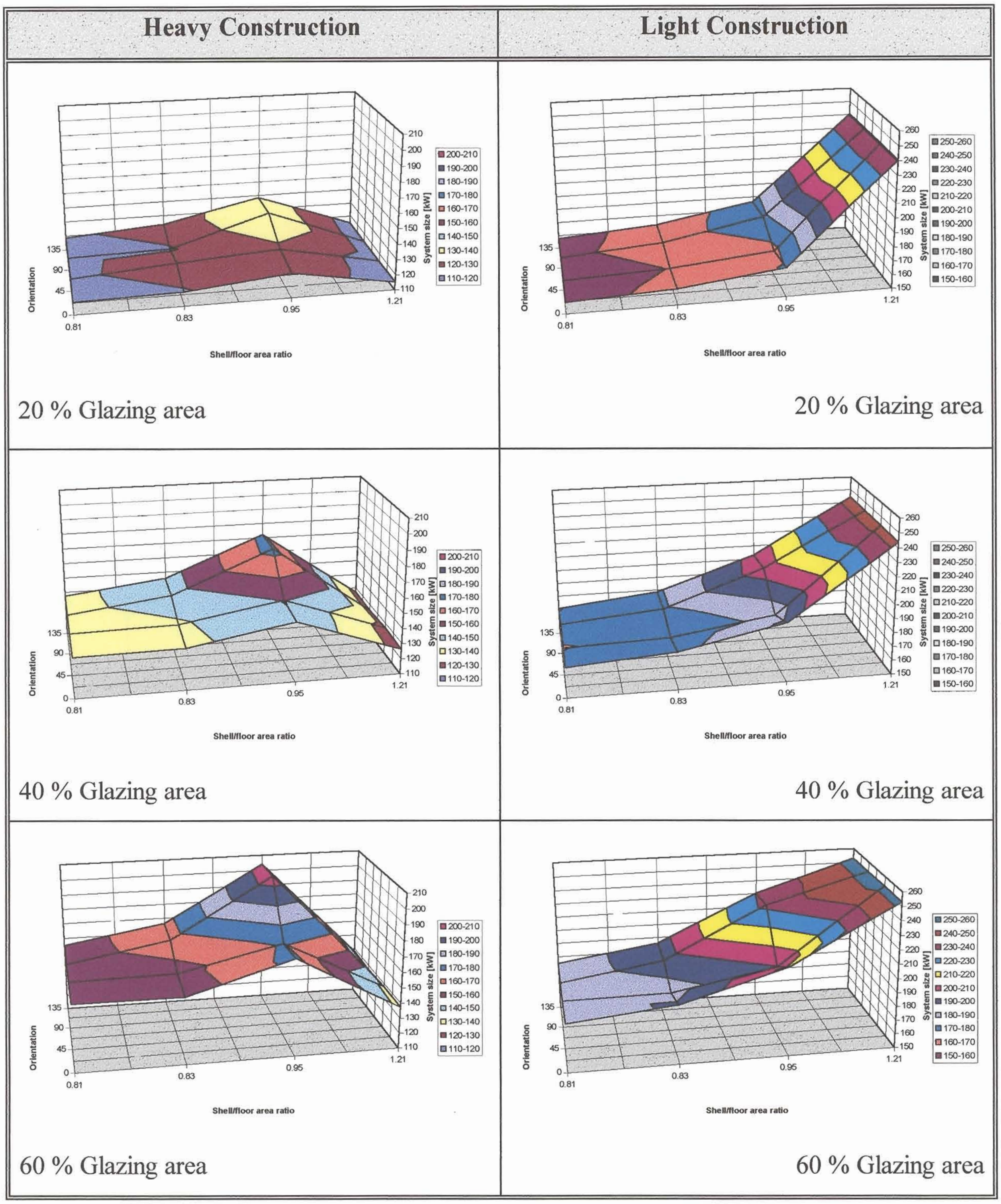


Figure 7.2 - Cooling system requirements for different configurations of a 2500m² office building located in Pretoria.

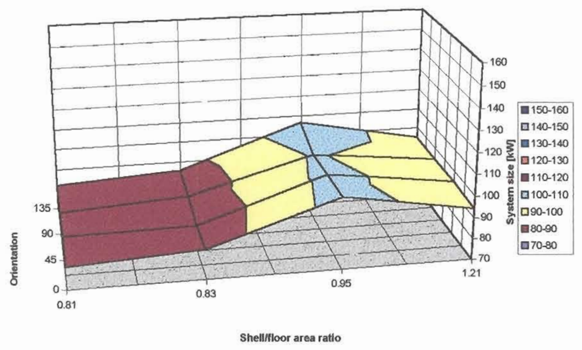
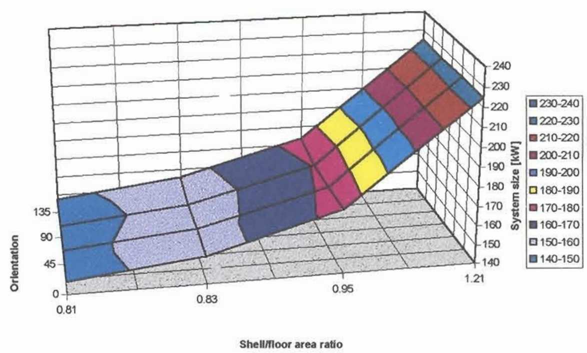
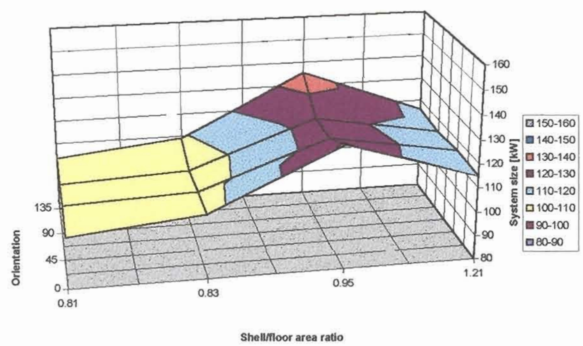
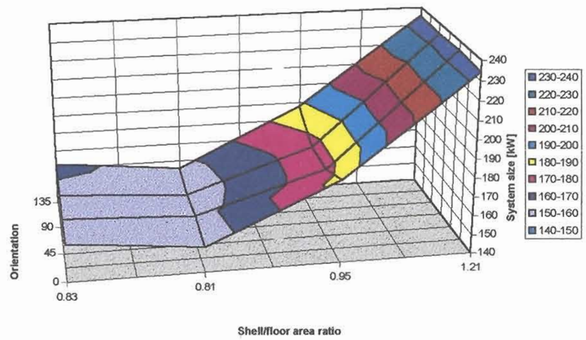
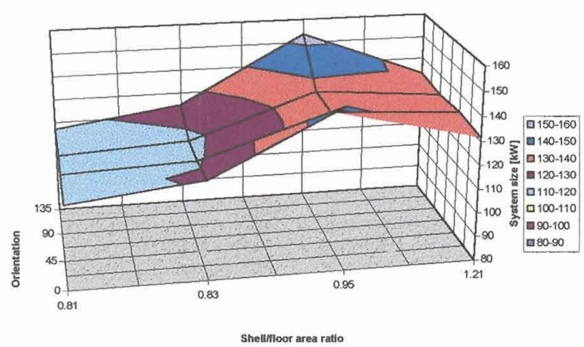
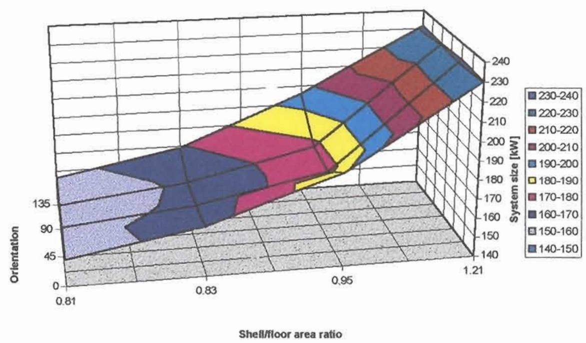
Heavy Construction	Light Construction
 20 % Glazing area	 20 % Glazing area
 40 % Glazing area	 40 % Glazing area
 60 % Glazing area	 60 % Glazing area

Figure 7.3 - Heating system requirements for different configurations of a 2500m² office building located in Pretoria.

The graphs clearly indicate that the abovementioned design variables greatly influence the HVAC system size. The required cooling capacity varies from 253 kW to 115 kW depending on their properties. Similarly, the heating system size can be decreased from 235 kW to 80 kW. The effect that the different design variables had on this reduction is addressed in more detail in the following paragraphs.

7.3.1 Building construction

Thermal resistance and mass of the building construction influence the characteristics of the building. The resistance is an indication of how easy heat is transferred through the building shell. It is expressed in terms of an overall heat transfer coefficient U (W/m^2 K). The lower the coefficient, the smaller the heat gain or loss.

Thermal mass, product of mass and specific heat, determines the heat storage characteristic of the building. This in turn determines the thermal lag and therefore the relationship between heat gain and HVAC load [3]. Figure 7.4 indicates this relation between instantaneous load and the actual cooling load for different thermal mass configurations.

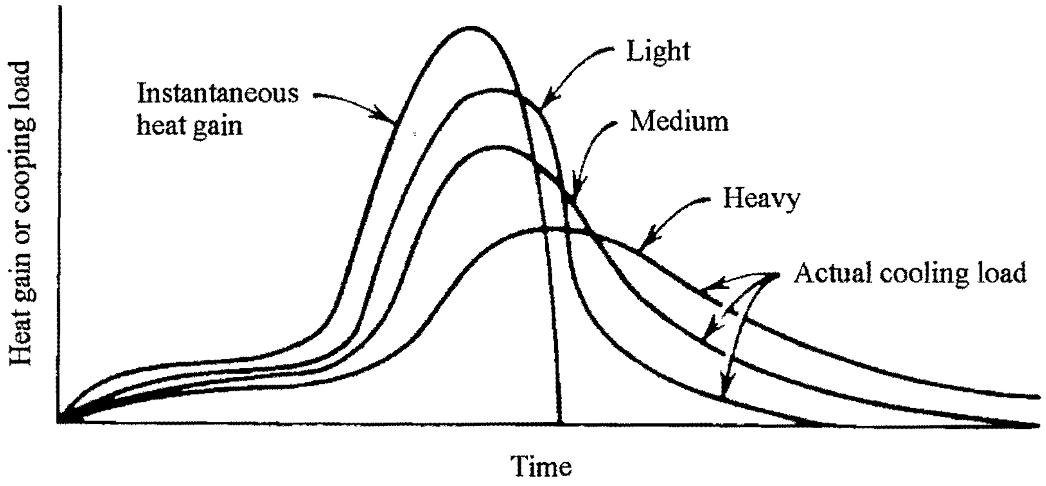


Figure 7.4 - Effect of thermal mass on HVAC system size [3].

Two construction configurations were tested. The first configuration consisted of a face brick and concrete combination for the walls with a cast concrete roof. The second consisted of a face brick and common brick combination with clay tile roofing. The second, lighter construction required a 40 % larger system on average.

7.3.2 Building form

Thermally efficient buildings usually enclose the largest volume for the least surface area. The heat exchange area of the building is thus effectively minimised. The benefit of a small surface to floor ratio (SF) can clearly be seen in the light construction building. There is an average reduction of 32% in system size between 50x50m single story building[1] and the double story 35x35m building[2].

The advantage of having a small SF ratio is less apparent for the heavy construction building. Glazing area and its orientation are the dominant factors for this building. Glazing area is expressed as a percentage of the wall area for the purpose of this study. The actual window area for the different building forms consequently varies. The influence of building form can be noted in the marginal increase in system size with a 28% increase in widow area, when comparing the performance of the 35x35m building to that of the 50x50m building.

7.3.3 Glazing area

Glazing area affects the amount of solar radiation that enters the building. The larger the area, the more solar energy is introduced into the building. This additional heat gain directly influences the cooling system size. Cooling requirements for the office building were increased by as much as 18% by changing the window to wall ratio from 20% to 40%. The effect of natural lighting has however not been taken into consideration.

Window size also adversely affects the heating system size. This is due to radiation heat loss from the warm interior to the cold exterior. The result further indicates that a slight improvement can be obtained by increasing the area of the windows facing east. This is due to the simplification of regarding the whole building as a single zone. The heat gain is thus

[1] Surface to floor ratio = 1.22

[2] Surface to floor ratio = 0.81

dispersed evenly throughout the building. In reality this would most likely result in the eastern side of the building being uncomfortable for the occupants.

7.3.4 Orientation

Solar radiation is a function of intensity and incident angle. The eastern and western façade of the building therefore receive a higher level of energy early in the morning and late in the afternoon. It is a well-known fact that buildings should be orientated with the longest axis running in an east-west direction. A 3% to 10% reduction can be obtained by properly orientating the buildings with a rectangular shape.

7.4 SYSTEM SELECTION

The analysis indicates that the heavyweight double story 35m by 35m building with 20% glazing has the best overall thermal performance. This building is thus chosen for the purposes of this demonstration. The cooling system required for this building is dominant due to the climate of Pretoria being mostly hot with a low humidity. A preliminary cooling system selection can be made using the HVAC selection tool. The assumptions concerning the system requirements and limitations are given in the following paragraphs.

It is assumed that the building is being developed as a multi-tenant office space. The interior architecture of the building is mostly open plan. Partition walls divide the space into eight areas for different tenants. These areas consist of perimeter, as well as interior zones. Space required by the ducting and chilled water piping is the only other building restriction imposed on the system. Ceiling-void height is limited so that building regulation concerning floor to ceiling elevation can be met without increasing the building size [4].

Aesthetic limitations imposed are that, window mounted units may not be used, and equipment within the zones should be kept to a minimum. Ventilation grilles and roof-mounted equipment may however be incorporated into the design. Fresh air and make-up air requirements must be supplied by the system. Only intermediate filtration, noise and humidity control is needed for a general office building. There is also no abnormal source of indoor contaminants. Cross-contamination between tenant areas must however be limited.

Zone loads will vary, since different tenants occupy the building. Separate metering of system use is thus needed for billing purposes. Individual control of the setpoint will further be required to accommodate their different preferences. It is also highly likely that the interior layout of the building will change as tenants come and go. In this process, some of the zones may become empty for short periods of time. The building manager must be able to switch off the supply to these zones.

Other administrative requirements are that the system be managed from a central point. It must thus be compatible with a suitable Building Management System (BMS). The building will also not have maintenance personnel. A suitable contract will be made with a building maintenance contractor. Maintenance within occupied areas must be kept to a minimum so as not to inconvenience the tenants.

It is assumed that the developer requires the building to be a medium term investment. System cost is therefore evaluated for a 10 year life-cycle. The above-mentioned assumptions are used to determine the relevant screening factors (Refer to Table 5.1 in Chapter 5). The relative importance of obtaining the imposed restrictions and limitations were taken to be:

- building restrictions - 5%,
- aesthetic restrictions - 5%,
- indoor air quality - 10%,
- building management - 10%,
- maintenance - 10%,
- flexibility - 20%, and
- cost - 40%.

By applying the screening factors and design goals, the preliminary selection tool is used to rank the suitability of the sixteen generic system types. Table 7.1 indicates their ranking. The detailed evaluation matrix is provided in Appendix D. The tool suggests the all-air, air-cooled system types, systems 1,2 and 3, be evaluated in more detail. Detailed analysis is thus reduced from sixteen potential candidates to only three.

System description	Value	Ranking
All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	320	1
Packaged rooftop units	316	2
All-air, variable volume, economiser system and air-cooled refrigeration plant.	314	3
All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	311	4
All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	306	5
All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	300	6
Four-pipe system with air-cooled refrigeration plant.	295	7
Two-pipe system with air-cooled refrigeration plant.	291	8
All-air, variable volume, economiser system and water-cooled refrigeration plant.	285	9
All-air, dual duct system with air-cooled refrigeration plant.	284	10
Split systems	279	11
All-air, dual duct system with water-cooled refrigeration plant.	277	12
Four-pipe system with water-cooled refrigeration plant.	263	13
Two-pipe system with water-cooled refrigeration plant.	261	14
Through the wall console units	234	15
Window units	207	16

Table 7.1 - System ranking for the hypothetical building

The choice of an air-cooled refrigeration system for this type and size of building corresponds to an analysis performed by Wilson and Nugent [5]. In general, the results of the tool can be considered as a good choice. It is however not always the best. The choice depends heavily upon the criteria evaluated and available systems. In this case a, combination of the rooftop packaged units and VAV system will probably be the best.

7.5 POTENTIAL IMPACT OF THE DESIGN TOOLS

The impact of the thermal analysis can clearly be seen in the large difference in HVAC system size for different building configurations. The results are even more impressive considering that not all the possible configuration were tested. Insulation and shading of the windows are typical examples of other building characteristics that affects building thermal efficiency.

The analysis indicated that a reduction in HVAC size of around 55% can be obtained. It is however highly unlikely that an architect will perform more than five simulations. Restrictions due to property size and aesthetics also play a role. A more realistic value will typically be in the order of 10% reduction in energy usage [2].

Using the selection tool also impacts the future success of the building. An experienced designer will be able to make an appropriate system choice without using the tool but the tool is a great communication aid. Communication or the lack thereof, between the different design team members is one of the major reasons why building system designs fail [6]. The tool can be used to obtain critical input and requirements from all the role players. Second-guessing as to system choice is thus reduced. The other design disciplines will also be better equipped to make provision for the HVAC system requirements.

7.6 CONCLUSION

Using the simplified preliminary design tools, an extensive building and system analysis was performed without the need for detailed information. This type of analysis can typically be done during the initial project meeting. This will improve communication between the different role players. The end result being a more energy efficient and comfortable building design.

7.7 BIBLIOGRAPHY

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Chapter 8 Closure

This chapter provides a brief overview of the work and contributions of this study. It also provides recommendations for future work.

8.1 SUMMARY

Building designers are increasingly pressured to design buildings with high standards of energy efficiency, performance and comfort. Computer design tools have a huge potential for aiding designers in achieving these design objectives. These tools have so far failed to be incorporated into general design practice. Complexity of existing tools seems to be the biggest stumbling block. A need for simplified design tools that aid designers in improving the thermal efficiency of buildings and selecting a preliminary HVAC system was identified.

Thermal efficiency of a building is largely determined by architectural design decisions made during the preliminary design stages. A new simplified design tool was thus developed for use by architects. In order to simplify the tool it was necessary to reduce input complexity and data required by the tool. This was done by identifying and focusing on critical design parameters. A rating scheme was also developed to further facilitate the evaluation of building thermal performance. The new tool was extensively verified and tested to establish confidence and credibility in its use.

HVAC system selection requires a detailed analysis to compare and evaluate the different system characteristics. This is however hardly ever done, as it is complex and very time consuming. A simplified preliminary selection tool was developed to aid designers in this respect. The new tool improves on other existing tools by combining the simplicity of numerical ranking methods with the proficiency of expert systems. The tool further enhances communication between the designer and building developer by incorporating the whole team in ranking the importance of attaining certain design goals.

In order to demonstrate their function, the above mentioned simplified design tools were applied to design a hypothetical office building. Using these tools it was possible to perform an extensive building and system analysis without the need for detailed information. The influence that various architectural design decisions have on thermal efficiency was analysed. Results indicate that there is approximately a 60% difference in HVAC system size between the worst and best building configuration evaluated.

The main benefits of the selection tool are that designers do not focus only on familiar systems, and that the tool aids HVAC designers in establishing the needs and requirements of the building developer.

This study shows that design tools need not be complex or difficult to use in order to be beneficial to designers. It is believed that the new tools will contribute to improving building efficiency and comfort without further complicating the existing design methodology. The study objectives identified in Chapter 1 have thus been successfully addressed.

8.2 RECOMMENDATIONS FOR FURTHER WORK

The simplified design tools developed during this study can greatly assist practising designers. Certain aspects of their function and use can however be improved. These items are identified here as areas for future work.

1. The verification analysis indicated that the simplified design tool has the potential to be used in more detailed analysis. It is proposed that the preliminary design tool be integrated into a detailed design tool. The initial building model is generated using the simplified user interface. An advanced user can edit the model where necessary via a detailed user interface. This will mostly consist of providing detailed ventilation and internal load data. This enables engineers to also benefit from the simplified building description.

2. The exchange of data between different design applications was identified as one of the requirements of new design tools. Currently, the new thermal design tool does not make any provision for this. This aspect still needs to be addressed.

3. Natural lighting is also influenced by architectural design decisions. Reducing window size, for example, may improve the thermal characteristics of the building but it can adversely affect savings due to the use of natural lighting. A simplified method for taking this into considerations must be developed.

4. The rating scheme developed during this study uses the normalised average of the heating and cooling system requirements as basis for determining building efficiency. However, buildings subject to warm climatic conditions for the largest part of the year need to be more efficient towards reducing the cooling load, and visa versa. The rating scheme can be improved by using a weighted ratio of the winter and summer requirements. The number of heating and cooling days for a particular climate can typically be used as weighing factor.

5. The building thermal rating scheme must be extended to incorporate the other building types.

6. The selection tool prototype developed during this study currently only evaluates and rates a few generic cooling system types. There is thus a huge scope for extending the tool to include new system types and selection criteria. Another aspect that needs attention is the use of multiple systems. Currently the selection tool does not take this into account. It is however a common HVAC system solution.

Appendix A

DEFAULT DESIGN DATA

A.1 INTRODUCTION

This appendix provides the typical South African wall, roof and floor constructions as well as other default design data used in the preliminary architectural design tool. A material database is also provided. The different construction configurations are defined in terms of this database.

A.2 MATERIAL DATABASE

Code No.	Description	k W/(m K)	ρ kg/m³	C_p kJ/(kg K)
0	Acoustic tile	0.061	481	0.84
1	Acoustone	0.080	258	1.00
2	Asbes/cement shingles	0.270	1900	1.00
3	Asbestos Cement Pressed	0.620	2100	0.83
4	Asbestos Cement Unpressed	0.480	1830	0.84
5	Ashcrete	0.330	753	1.20
6	Ashpalt Shingles	0.125	1100	1.26
7	Asphalt	1.230	2243	1.67
8	Bitumen	0.160	1050.000	0.84
9	Brickwork (common)	0.727	1922	0.84
10	Carpet	0.045	120.000	1.00
11	Cast concrete h.w.	1.737	2243	0.84
12	Cast concrete l.w.	0.173	641	0.84
13	Concrete block h.w.	0.813	977	0.84
14	Concrete block h.w.	1.038	977	0.84
15	Concrete block l.w. (filled)	0.138	288	0.84
16	Concrete block h.w. (filled)	0.588	849	0.84
17	Concrete block l.w.	0.381	609	0.84
18	Concrete block l.w.	0.571	609	0.84
19	Concrete Panels	0.930	2300.000	0.65
20	Corrugated Iron	7870.000	447	0.80
21	Ergolite	0.040	16	0.84
22	Expanded Polystyrene	0.035	25	1.40
23	Face brick	1.333	2002	0.92
24	Felt Undercarpet	0.045	120	1.00
25	Fibreboard	240.000	0.058	1.46
26	Fibreglass	0.045	12	1.00
27	Fibretone	0.036	84	1.00
28	Glass	0.750	2483	0.67
29	Glass Wool	0.040	25	1.00
30	Granite	2.930	2643.000	0.92

Table A.1 - Material database [1,2]

Code No.	Description	k W/(m K)	ρ kg/m³	C_p kJ/(kg K)
31	Gypsum Plaster Board	0.160	950	0.84
32	Hardboard	0.200	1121	1.36
33	Insulation	0.043	91	0.84
34	Metal facing	44.998	7689	0.42
35	Mild Steel	53.000	7850	0.50
36	Paper Honeycomb	0.180	1.1	1.00
37	Perlite	0.130	640	0.42
38	Perlite Honeycomb	0.110	66	1.00
39	Plaster	0.480	1442	0.88
40	Preformed Slab W&C	1.280	352	0.80
41	PVC Floor Covering	0.400	120	1.00
42	Q-Lite Translucent	0.220	2400	0.80
43	Sand Building	0.300	1500	0.84
44	Slate	1.400	2500	0.75
45	Soil	0.850	1500	1.50
46	Steves	0.004	50	0.96
47	Stone	2.800	2400	0.79
48	Stucco	0.692	1858	0.84
49	Subfloor	0.115	512	0.80
50	Tiles Asphalt	1.230	243	1.46
51	Tiles Burnt Clay	0.840	1922	0.92
52	Tiles Linoleum	0.350	1750	1.26
53	Vermiculite	0.065	100	0.88
54	Wood Hardwood	0.150	720	1.63
55	Wood Pine	0.150	660	1.40
56	Wood Ply-	0.140	530	1.40
57	Wood Teak	0.170	700	1.40

Table A.1 - Material database (Continued)

Some construction configuration incorporates the use of an airspace. The thermal properties of these "building materials" are defined in terms of its thermal resistance R per unit area.

Code No.	Description	R (m K) / W
54	Air space resistance	0.161
55	Airspace ceiling	0.176

Table A. 2 - Airspace thermal resistance

A.3 STANDARD WALLS

No.	Description	Layer Codes Outside to Inside	Thickness Outside to Inside	α[1] %
A	**Brickwork**			
1	Single brick	1,9	110	75
2	Single brick with 13mm plaster	2,9,35	110,13	75
3	Double brick	2,9,9	110,110	75
4	Double brick with 13mm plaster	3,9,9,35	110,110,13	75
5	Double brick, airspace, 10mm plasterboard	4,9,9,54,27	110,110,50,10	75
6	Brick, airspace brick with 13mm plaster	4,9,54,9,35	110,50,110,13	75
B	**Stone**			
7	Stone	1,47	200	70
8	Stone, 13mm plaster	2,43,35	200,13	70
9	stone, airspace, 10mm plasterboard	3,43,54,27	200,50,10	70
C	**Concrete blocks**			
10	100mm l.w. concrete block with 13mm plaster	2,12,35	100,13	65
11	100mm l.w. concrete block, airspace, 10mm plasterboard	3,12,54,27	100,50,10	65
12	200mm l.w. concrete block with 13mm plaster	2,13,35	200,13	65
13	200mm l.w. concrete block, airspace, 10mm plasterboard	3,13,54,27	200,50,10	65
D	**Cast Concrete and Pre Cast Panels**			
14	150mm l.w. cast concrete	1,11	150	65
15	200mm l.w cast concrete	1,11	200	65
16	150mm l.w. cast concrete, 50mm wood wool slab, 13mm plaster	3,11,21,35	150,50,13	65
17	200mm l.w cast concrete, 50mm wood wool slab, 13mm plaster	3,11,21,35	200,50,13	65
E	**Face Brick**			
18	Face Brick	1,19	100	75
19	Face Brick 10mm plasterboard	2,19,27	100,10	75
20	Face brick, common brick with 13mm plaster	3,19,9,35	100,110,13	75
21	Face brick, common brick, airspace, 10mm plasterboard	4,19,9,54,27	100,110,50,10	75
22	Face brick, airspace, common brick, 13mm plaster	4,19,54,9,35	100,50,110,13	75
23	Face brick, l.w. concrete block with 13mm plaster	3,19,12,35	100,100,13	75
24	Face brick, l.w. cast concrete, 13mm plaster	3,19,11,35	100,150,13	75
F	**Brickwork + Material X**			
25	13mm plaster, brick, face brick	3,35,9,19	13,110,100	60
26	13mm plaster, brick, airspace, face brick	4,35,9,54,19	13,110,50,100	60
27	13mm plaster, brick, l.w. concrete block, 13mm plaster	4,35,9,12,35	13,110,100,13	60
28	13mm plaster, brick, airspace, l.w. concrete block, 13mm plaster	5,35,9,54,12,35	13,110,50,100,13	60
29	13mm plaster, brick, l.w. cast concrete	3,35,9,11	13,110,150	60
30	13mm plaster, brick, airspace, l.w. cast concrete	4,35,9,54,11	13,110,50,150	60

Table A. 3 - Standard wall configurations

[1] Absorptance

No.	Description	Layer Codes Outside to Inside	Thickness Outside to Inside	α %
G	**Stone + Material X**			
31	Stone, brick, 13mm plaster	2,43,9,35	100,100,13	70
32	Stone, airspace, brick 13mm plaster	4,43,54,9,35	100,50,110,13	70
33	Stone, l.w. concrete block, 13mm plaster	3,43,12,35	100,100,13	70
34	Stone, airspace, l.w. concrete block, 13mm plaster	4,43,54,12,35	100,50,100,13	70
35	Stone, l.w. cast concrete	2,43,11	100,150	70
36	Stone, airspace, l.w. cast concrete	3,43,54,11	100,50,150	70
H	**100mm Concrete block + Material X**			
37	13mm plaster, 100mm l.w. conc. block, face brick	3,35,12,19	13,100,100	60
38	13mm plaster, 100mm l.w. conc. block, airspace, face brick	4,35,12,54,19	13,100,50,100	60
39	100mm l.w. conc. block, 100mm l.w. conc. block, 13mm plaster	3,12,12,35	100,100,13	65
40	100mm l.w. conc. block, airspace 100mm l.w. conc. block, 13mm plaster	4,12,54,12,35	100,50,100,13	65
41	100mm l.w. conc. block, 150mm l.w. cast conc. , 13mm plaster	3,12,11,35	100,150,13	65
42	100mm l.w. conc. block, airspace 150mm l.w. cast conc., 13mm plaster	4,12,54,11,35	100,50,150,13	65
I	**150mm Cast Concrete + Material X**			
43	150mm l.w. cast conc., face brick	2,11,19	150,100	65
44	150mm l.w cast conc., airspace, face brick	3,11,54,19	150,50,100	65
45	150mm l.w. cast conc., 100mm l.w. conc. block, 13mm plaster	3,11,12,35	150,100,13	65
46	150mm l.w. cast conc., airspace 100mm l.w. conc. block, 13mm plaster	4,11,54,12,35	150,50,100,13	65
47	150mm l.w. cast conc., 100mm cast conc. , 13mm plaster	3,11,11,35	150,100,13	65
48	150mm l.w. cast conc., airspace 100mm cast conc. , 13mm plaster	4,11,54,11,35	150,50,100,13	65
J	**Corrugated Iron + Material X**			
49	24 Gauge Corrugated Iron	1,16	2	70
50	24 Gauge Corrugated Iron, airspace, 13mm Ins. Board	3,16,54,21	2,50,13	70
51	24 Gauge Corrugated Iron, airspace, 20mm Wood	3,16,54,51	2,50,20	70
K	**Wood**			
52	20mm Wood	1,50	20	70
53	20mm wood, airspace, 10mm plasterboard	3,50,54,27	20,50,10	70
L	Partition wall			
54	Metal facing, glass/wood/cotton fibre, metal facing	3,30,22,30	2,50,2	70
55	Metal facing, paper honeycomb, metal facing	3,30,32,30	2,50,2	70
56	Metal facing, paper honeycomb with perlite fill, metal facing	3,30,34,30	2,50,2	70
57	Metal facing, fibreboard, metal facing	3,30,21,30	2,50,2	70
58	Metal facing, wood shredded, metal facing	3,30,52,30	2,50,2	70
59	Metal facing, expanded vermiculite, metal facing	3,30,49,30	2,50,2	70
60	Metal facing, perlite, metal facing	3,30,33,30	2,50,2	70
61	25mm plasterboard, 25mm airspace, 25mm plasterboard	3,27,54,27	25,25,25	70
62	12mm fibreboard, 25mm airspace, 12mm fibreboard	3,21,54,21	12,25,12	70

Table A. 3 - Standard wall configurations (Continued)

A.4 STANDARD ROOFS

Roof types that include insulation are not represented in this table in order to save space. Insulated roofs have an additional fifty millimetres of insulation (material 29).

No.	Description	Layer Codes Outside to Inside	Thickness Outside to Inside	α %	ε_s[2] %
A	**Metal Deck**				
1	Steel deck	1,31	2	70	90
2	Steel deck, airspace, 20mm plaster or gypsum ceiling	3,31,55,27	2,300,20	70	90
3	Steel deck, airspace, acoustic tile	3,31,55,0	2,300,19	70	90
B	**Pre-Cast slabs**				
4	Precast slab	1,36	150	65	90
5	Pre-cast slab, airspace, 20mm plaster or gypsum ceiling	3,36,55,27	150,300,20	65	90
6	Pre-cast slab, airspace, acoustic tile	3,36,55,0	150,300,19	65	90
7	19mm asphalt, 75mm screed, pre-cast slab	3,8,35,36	19,75,150	55	5
8	19mm asphalt, 75mm screed, pre-cast slab, airspace, 20mm plaster or gypsum ceiling	5,8,35,36,55,27	19,75,150,300,20	55	5
9	19mm asphalt, 75mm screed, pre-cast slab, airspace, acoustic tile	5,8,35,36,55,0	19,75,150,300,19	55	5
D	**150mm l.w. cast concrete**				
10	150mm l.w. concrete	1,11	150	65	90
11	150mm l.w. concrete, airspace, 20mm plaster or gypsum ceiling	3,11,55,27	150,300,20	65	90
12	150mm l.w. concrete, airspace, acoustic tile	3,11,55,0	150,300,19	65	90
13	19mm asphalt, 75mm screed, l.w. concrete	3,8,35,11	19,75,150	55	5
14	19mm asphalt, 75mm screed, l.w. concrete, airspace, 20mm plaster or gypsum ceiling	5,8,35,11,55,27	19,75,150,300,20	55	5
15	19mm asphalt, 75mm screed, l.w. concrete, airspace, acoustic tile	5,8,35,11,55,0	19,75,150,300,19	55	5
16	Linoleum tiles, l.w. concrete	2,48,11	5,150	50	93.1
17	Linoleum tiles, l.w. concrete, airspace, 20mm plaster or gypsum ceiling	4,48,11,55,27	5,150,300,20	50	93.1
18	Linoleum tiles, l.w. concrete, airspace, acoustic tile	4,48,11,55,0	5,150,300,19	50	93.1
19	Carpet, l.w. concrete	2,10,11	5,150	50	30
20	Carpet, l.w. concrete, airspace, 20mm plaster or gypsum ceiling	4,10,11,55,27	5,150,300,20	50	30
21	Carpet, l.w. concrete, airspace, acoustic tile	4,10,11,55,0	5,150,300,19	50	30
E	**Wood**				
22	Hard wood	1,50	20	70	90
23	Hardwood, airspace, 20mm plaster or gypsum ceiling	3,50,55,27	20,300,20	70	90
24	Hardwood, airspace, acoustic tile	3,50,55,0	20,300,19	70	90

Table A. 4 - Standard roof configurations

[2] Long-wave emmitance

No.	Description	Layer Codes Outside to Inside	Thickness Outside to Inside	α %	ε_e %
F	**Asphalt singles**				
25	Asphalt shingles & 8mm pine wood	2,6,51	10,8	90	80
26	Asphalt singles, airspace, 20mm plaster or gypsum ceiling	3,6,55,27	10,300,20	90	80
27	Asphalt singles, airspace, acoustic tile	3,6,55,0	10,300,19	90	80
G	**Asbestos-cement singles**				
28	Asbestos-Cement Shingles & 8mm pine wood	2,2,51	10,8	65	90
29	Asbestos-cement singles, airspace, 20mm plaster or gypsum ceiling	3,2,55,27	10,300,20	65	90
30	Asbestos-cement singles, airspace, acoustic tile	3,2,55,0	10,300,19	65	90
H	**Slate tiles**				
31	Slates tile & 8mm pine wood	2,40,51	10,8	90	90
32	Slate singles, airspace, 20mm plaster or gypsum ceiling	3,44,59,31	10,300,20	90	90
33	Slate singles, airspace, acoustic tile	3,44,59,0	10,300,19	90	90
I	**Sheet metal**				
34	Sheet metal & 8mm pine wood	2,16,51	2,8	70	90
35	Sheet metal, airspace, 20mm plaster or gypsum ceiling	3,16,55,27	2,300,20	70	90
36	Sheet metal, airspace, acoustic tile	3,16,55,0	2,300,19	70	90
J	**Wood singles**				
37	Wood shingles & 25x100mm strips	2,50,52	10,25	70	90
38	Wood shingles & 8mm plywood	2,50,52	10,8	70	90
39	Wood shingles, airspace, 20mm plaster or gypsum ceiling	3,50,55,27	10,300,20	70	90
40	Wood shingles, airspace, acoustic tile	3,50,55,0	10,300,19	70	90

Table A. 4 - Standard roof configurations (Continued)

A.5 STANDARD FLOORS

No.	Description	Layer Codes Inside to Outside	Thickness Inside to Outside
A	**Concrete & Ground**		
1	20 mm screed, 150 mm l.w concrete, ground	2,35,11	20,150
2	Linoleum tile, 150 mm l.w concrete, ground	2,48,11	5,150
3	Clay tile, 150mm l.w. concrete, ground	2,47,11	5,150
4	25 mm hardwood, 150 mm l.w. concrete, ground	2,50,11	5,150
5	Carpet, 150mm l.w. concrete, ground	2,10,11	5,150
B	**150 mm l.w. concrete**		
6	150 mm l.w. concrete	1,11	150
7	150 mm l.w. concrete, airspace, 20 mm plaster or gypsum ceiling	3,11,55,27	150,300,20
8	150 mm l.w. concrete, airspace, acoustic tile	3,11,55,0	150,300,19
9	Linoleum tiles, l.w. concrete	2,48,11	5,150
10	Linoleum tiles, l.w. concrete, airspace, 20 mm plaster or gypsum ceiling	4,48,11,55,27	5,150,300,20
11	Linoleum tiles, l.w. concrete, airspace, acoustic tile	4,48,11,55,0	5,150,300,19
12	Clay tiles, l.w. concrete	2,47,11	5,150
13	Clay tiles, l.w. concrete, airspace, 20 mm plaster or gypsum ceiling	4,47,11,55,27	5,150,300,20
14	Clay tiles, l.w. concrete, airspace, acoustic tile	4,47,11,55,0	5,150,300,19
15	Carpet, l.w. concrete	2,10,11	5,150
16	Carpet, l.w. concrete, airspace, 20 mm plaster or gypsum ceiling	4,10,11,55,27	5,150,300,20
17	Carpet, l.w. concrete, airspace, acoustic tile	4,10,11,55,0	5,150,300,19
18	Hardwood, l.w. concrete	2,50,11	5,150
19	Hardwood, l.w. concrete, airspace, 20 mm plaster or gypsum ceiling	4,50,11,55,27	5,150,300,20
20	Hardwood, l.w. concrete, airspace, acoustic tile	4,50,11,55,0	5,150,300,19
C	**Wood**		
21	Hard wood	1,50	20
22	Hardwood, airspace, 20 mm plaster or gypsum ceiling	3,50,55,27	20,300,20
23	Hardwood, airspace, acoustic tile	3,50,55,0	20,300,19
24	Carpet, hardwood, airspace, 20 mm plaster or gypsum ceiling	4,10,50,55,27	5,20,300,20
25	Carpet, hardwood, airspace, acoustic tile	4,10,50,55,0	5,20,300,19

Table A.5 - Standard floor configurations

A.6 DEFAULT DESIGN DATA

Table A.6 provides the default design data used in the preliminary thermal design tool. These values are typical design values for South African conditions and may thus vary depending on country. These values were obtained from various literature sources and experience [3,4,5,6].

Building type	Internal load (W/ m²)	Occupancy (m²/ person)	Outdoor air (L/s/ person)	Operating hours	Setpoint
Office	26	10	10	07h00-18h00	24 S ; 22 W
Dep. stores	Varies[3]	Varies	7.5	09h00-18h00	24 S ; 22 W
Hotels	32	38	7.5	24 hours	27 S ; 22 W
Residences	8	38 Night time 114 Day time[4]	7.5[5]	06h00-8h00 (W) 13h00-22h00 (S)	27 S ; 22 W
Hospital	Varies[3]	10	11	24 hours	24 S ; 22 W
Factory	Varies[3]	100	15[6]	07h00-18h00	26 S ; 20 W
Places of assembly	12	7 (Winter)[7] 1.4 (Summer)	9	07h00-12h00 (W)[8] 13h00-18h00 (S)	24 S ; 22 W

Table A.6 - Default design data for various building types

3 Load can vary considerable depending on type of store, hospital or factory equipment being used and must this be specified.

4 It is assumed that only a third of the occupants are at home during the daytime.

5 Ventilation normally satisfied by infiltration and natural ventilation over entire 24-hour period.

6 Ventilation requirements depend on the factory processes. Processes using volatile chemical elements will require larger amounts of outdoor air to flush out contaminants than normal assembly factories.

7 It is assumed that only 20% of the auditorium is occupied for winter load calculation

8 Operating hours of an auditorium vary depending on its function. In South Africa these time usually will result in the highest system requirements for winter and summer respectively

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Appendix B

SUMMARY OF THE VERIFICATION DATA

B.1 SUMMARY OF BUILDING ZONES

In this appendix a summary of the verification data is given in tabular form. The following gives an overview of the major features of the 103 verification studies. The symbols used in the tables are: burro

- MZ - Multi-zone simulation performed? (Y/N)
- GC - Building zone in ground contact, or exterior, interior floor? (G,E,I)
- WO - Windows open during monitored period? (Y/N)
- HG - Heat generation (Internal load) in building zone? (Y/N)
- FA - Floor area of building zone (m^2).
- CON - Does exterior walls have the same construction? (Y/N)

Six studies are listed as YN in the WO column. This indicates that the windows were open and closed during the monitoring period as described in Chapter 3.

NO	BUILDING	LOCATION	DATE	MZ	GC	WO	HG	CON	FA
1	Experim1	Pretoria	07/06/82-13/06/82	N	G	N	N	Y	9
2	Experim2	Pretoria	07/06/82-13/06/82	N	G	N	N	Y	9
3	Experim3	Pretoria	07/06/82-13/06/82	N	G	N	N	Y	9
4	Experim4	Pretoria	07/06/82-13/06/82	N	G	N	N	Y	9
5	Experim1	Pretoria	26/07/82-01/08/82	N	G	N	N	Y	9
6	Experim2	Pretoria	26/07/82-01/08/82	N	G	N	N	Y	9
7	Experim3	Pretoria	26/07/82-01/08/82	N	G	N	N	Y	9
8	Experim4	Pretoria	26/07/82-01/08/82	N	G	N	N	Y	9
9	Experim1	Pretoria	27/09/82-03/10/82	N	G	Y	N	Y	9
10	Experim2	Pretoria	27/09/82-03/10/82	N	G	Y	N	Y	9
11	Experim3	Pretoria	27/09/82-03/10/82	N	G	Y	N	Y	9
12	Experim4	Pretoria	27/09/82-03/10/82	N	G	Y	N	Y	9
13	Experim1	Pretoria	13/07/82-19/08/82	N	G	Y	N	Y	9
14	Experim2	Pretoria	13/07/82-19/08/82	N	G	Y	N	Y	9
15	Experim3	Pretoria	13/07/82-19/08/82	N	G	Y	N	Y	9
16	Experim4	Pretoria	13/07/82-19/08/82	N	G	Y	N	Y	9
17	Experim1	Pretoria	14/02/83-20/02/83	N	G	Y	N	Y	9
18	Experim2	Pretoria	14/02/83-20/02/83	N	G	Y	N	Y	9

NO	BUILDING	LOCATION	DATE	MZ	GC	WO	HG	CON	FA
19	Experim3	Pretoria	14/02/83-20/02/83	N	G	Y	N	Y	9
20	Experim4	Pretoria	14/02/83-20/02/83	N	G	Y	N	Y	9
21	Experim1	Pretoria	18/04/84-26/04/84	N	G	Y	N	Y	9
22	Experim2	Pretoria	18/04/84-26/04/84	N	G	Y	N	Y	9
23	Experim4	Pretoria	18/04/84-26/04/84	N	G	Y	N	Y	9
24	Experim4	Pretoria	10/02/86-16/02/86	N	G	Y	Y	Y	9
25	Experim1	Pretoria	01/11/90-03/11/90	N	G	Y	Y	Y	9
26	Bedroom1	Centurion	18/08/86-24/08/86	N	G	N	N	Y	11
27	Bedroom1	Centurion	04/08/86-10/08/86	N	G	N	N	Y	11
28	Bedroom1	Centurion	21/10/85-27/10/85	N	G	Y	N	Y	11
29	Bedroom1	Centurion	25/11/85-01/12/85	N	G	Y	N	Y	11
30	Bedroom1	Centurion	04/11/85-17/11/85	N	G	Y	N	Y	11
31	Bedroom1	Centurion	21/07/86-27/07/86	N	G	Y	Y	Y	11
32	Bedroom2	Wingate Park	31/10/90-01/11/90	Y	G	N	Y	Y	11
33	Bedroom3	Moreleta Park	20/10/90-21/10/90	Y	I	N	Y	Y	8
34	Bathroom	Faerie Glen	19/10/90-21/10/90	Y	G	N	Y	N	4
35	Dormit1	Negev Desert	11/07/88-16/07/88	N	G	N	N	Y	23
36	Dormit1	Negev Desert	25/07/88-01/08/88	N	G	NY	N	Y	23
37	Dormit1	Negev Desert	01/08/88-08/08/88	N	G	Y	N	Y	23
38	Dormit2	Negev Desert	11/07/88-16/07/88	N	G	N	N	Y	23
39	Dormit2	Negev Desert	25/07/88-01/08/88	N	G	NY	N	Y	23
40	Dormit2	Negev Desert	01/08/88-08/08/88	N	G	Y	N	Y	23
41	Prefab	Negev Desert	11/07/88-16/07/88	N	E	N	N	Y	13
42	Prefab	Negev Desert	25/07/88-01/08/88	N	E	NY	N	Y	13
43	Prefab	Negev Desert	01/08/88-08/08/88	N	E	Y	N	Y	13
44	Garage	Centurion	27/01/86-02/02/86	N	G	N	N	N	18
45	Garage	Centurion	03/02/86-09/02/86	Y	G	Y	Y	N	18
46	Shop	Centurion	04/08/86-10/08/86	N	G	N	N	N	102
47	Shop	Centurion	21/07/86-27/07/86	N	G	Y	N	N	102
48	Shop	Centurion	27/01/86-16/02/86	N	G	Y	Y	N	102
49	School 1	Menlo Park	20/07/87-26/07/87	N	I	N	N	Y	58
50	School 1	Menlo Park	13/07/87-19/07/87	N	I	Y	N	Y	58
51	School 2	The Willows	17/02/90-18/02/90	N	G	Y	N	Y	51
52	Store 1	The Willows	20/10/90-23/10/90	Y	G	N	Y	N	13
53	Store 2	Volksrust	29/06/87-04/07/87	N	G	Y	N	Y	763
54	Studio	Brooklyn	09/11/91-10/09/91	N	G	N	N	N	340

NO	BUILDING	LOCATION	DATE	MZ	GC	WO	HG	CON	FA
55	Church	Arcadia	18/03/90-18/03/90	N	G	NY	Y	N	200
56	Factory	Groenkloof	11/11/85-24/11/85	N	G	NY	N	N	7755
57	Office1	CSIR Pretoria	09/04/84-15/04/84	N	I	N	N	Y	14
58	Office1	CSIR Pretoria	02/04/84-08/04/84	N	I	Y	N	Y	14
59	Office2	GH Marais	06/05/89-07/05/89	N	E	N	N	Y	34
60	Office3	GH Marais	06/05/89-07/05/89	N	I	N	N	Y	17
61	Office3	GH Marais	18/04/90-20/04/90	N	I	N	Y	Y	17
62	Office4	GH Marais	06/05/89-07/05/89	N	E	N	N	Y	12
63	Office5	Cent. Gov. Off.	18/02/89-21/02/89	N	I	N	Y	Y	29
64	Office6	Liberty Life	26/01/88-31/01/88	N	I	N	Y	N	22
65	Office7	Poyntons	12/04/89-16/04/89	N	I	N	N	N	21
66	Office8	UNISA Pretoria	11/04/89-14/04/89	N	I	N	N	Y	14
67	Office9	Eng. Block	20/10/90-21/10/90	Y	I	N	Y	Y	18
68	Office10	Eng. Block	20/10/90-21/10/90	Y	I	N	Y	N	21
69	Office11	JG Strijdom	20/10/90-21/10/90	Y	I	N	Y	Y	10
70	Office12	JG Strijdom	20/10/90-21/10/90	Y	I	N	Y	Y	14
71	Lightweight	Negev Desert	18/08/92-25/08/92	N	E	Y	N	Y	45.9
72	Heavyweight	Negev Desert	18/08/92-25/08/92	N	G	Y	N	Y	9.7
73	Lightweight	Negev Desert	24/08/92-30/08/92	N	E	Y	N	Y	45.9
74	Heavyweight	Negev Desert	24/08/92-30/08/92	N	G	NY	N	Y	9.7
75	Room 1-91	Pretoria	20/02/96-23/02/96	N	G	N	Y	Y	14.6
76	Room 1-90	Pretoria	20/02/96-23/02/96	N	G	N	Y	Y	14.6
77	Room 1-94	Pretoria	20/02/96-23/02/96	N	G	N	Y	Y	43.1
78	Room 1-93	Pretoria	20/02/96-23/02/96	N	G	N	Y	Y	33.2
79	Room 1-79	Pretoria	23/02/96-27/02/96	N	G	N	Y	Y	8.2
80	Room 1-80	Pretoria	23/02/96-27/02/96	N	G	N	Y	Y	8.2
81	Room 1-82	Pretoria	23/02/96-27/02/96	N	G	N	Y	Y	9.9
82	Room 1-83	Pretoria	23/02/96-27/02/96	N	G	N	Y	Y	14.5
83	Room 1-122	Pretoria	30/09/96-03/10/96	Y	G	N	Y	Y	31.6
84	Room 1-123	Pretoria	30/09/96-03/10/96	Y	G	N	Y	Y	31.6
85	Room 1-125	Pretoria	03/10/96-07/10/96	Y	G	N	Y	Y	8.3
86	Room 1-126	Pretoria	03/10/96-07/10/96	Y	G	N	Y	Y	8.3
87	Room 1-127	Pretoria	03/10/96-07/10/96	Y	G	N	Y	Y	16.7
88	Room 1-141	Pretoria	01/03/96-05/03/96	N	G	N	Y	Y	18.8
89	Room 1-142	Pretoria	01/03/96-05/03/96	N	G	N	Y	Y	18.8
90	Room 1-143	Pretoria	01/03/96-05/03/96	N	G	N	Y	Y	18.8

NO	BUILDING	LOCATION	DATE	MZ	GC	WO	HG	CON	FA
91	Room 1-145	Pretoria	01/03/96-05/03/96	N	G	N	Y	Y	18.8
92	Room 1-7	Pretoria	12/03/96-15/03/96	N	G	N	Y	Y	27
93	Room 1-7	Pretoria	15/03/96-18/03/96	N	G	N	Y	Y	27
94	Room 1-9	Pretoria	12/03/96-15/03/96	N	G	N	Y	Y	30.5
95	Room 1-9	Pretoria	15/03/96-18/03/96	N	G	N	Y	Y	30.5
96	Sasol-E	Secunda	09/09/95-15/09/95	N	I	Y	Y	Y	683.9
97	Sasol-F	Secunda	23/09/95-29/09/95	N	G	Y	Y	Y	135.7
98	Sasol-N	Secunda	16/09/95-22/09/95	N	G	Y	Y	Y	911.8
99	Sasol-N	Secunda	09/09/95-15/09/95	N	I	Y	Y	Y	911.8
100	Sasol-S	Secunda	16/09/95-22/09/95	N	G	Y	Y	Y	911.8
101	Sasol-S	Secunda	09/09/95-15/09/95	N	I	Y	Y	Y	911.8
102	Sasol-W	Secunda	16/09/95-22/09/95	N	G	Y	Y	Y	683.9
103	Sasol-W	Secunda	09/09/95-15/09/95	N	I	Y	Y	Y	683.9

B.2 SUMMARY OF THE DESIGN TOOL INPUT REQUIREMENTS.

The following table summarises the required input for the design tool. The number indicated in the floor, roof and wall construction corresponds with the default construction given in Appendix A. Bold numerals indicate that the building zone was fitted with insulation. Fifty-millimetre insulation was added to the default construction for these zones. The columns marked I, indicates if the surface is an internal surface.

NO.	BUILDING ZONE	LOCATION	N WALL LENGTH (M)	HEIGHT (M)	FLOOR AREA (M²)	NO. OF STORIES	NORTH GLAZING (%)	I	EAST GLAZING (%)	I	SOUTH GLAZING (%)	I	WEST GLAZING (%)	I	GLASS TYPE	SHADING	PEOPLE	LOADS (W/m²)	AZIMUTH ANGLE (Deg.)	WALL TYPE	ROOF TYPE	FLOOR TYPE
1	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	1
2	Experim2	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	1
3	Experim3	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	32	1
4	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	13	1
5	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	5
6	Experim2	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	5
7	Experim3	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	32	5
8	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	13	5
9	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	1
10	Experim2	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	1
11	Experim3	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	32	1
12	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	13	1
13	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	5
14	Experim2	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	5
15	Experim3	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	32	5
16	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	13	5
17	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	**2**	1
18	Experim2	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	**2**	5
19	Experim3	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	**32**	5

NO.	BUILDING ZONE	LOCATION	N WALL LENGTH (M)	HEIGHT (M)	FLOOR AREA (M²)	NO. OF STORIES	NORTH GLAZING (%)	I	EAST GLAZING (%)	I	SOUTH GLAZING (%)	I	WEST GLAZING (%)	I	GLASS TYPE	SHADING	PEOPLE	LOADS (W/m²)	AZIMUTH ANGLE (Deg.)	WALL TYPE	ROOF TYPE	FLOOR TYPE
20	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	13	5
21	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	5
22	Experim2	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	2	5
23	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	32	5
24	Experim4	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	288.9	0	4	13	5
25	Experim1	Pretoria	3.0	3.00	9.0	1	8.9	N	0.0	N	8.9	N	0.0	N	Ordinary	Heavy	0	262.2	0	4	2	5
26	Bedroom1	Centurion	3.5	2.45	11.0	1	21.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	0	13	4	2	5
27	Bedroom1	Centurion	3.5	2.45	11.0	1	21.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	0	13	4	2	5
28	Bedroom1	Centurion	3.5	2.45	11.0	1	21.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	0	13	4	2	5
29	Bedroom1	Centurion	3.5	2.45	11.0	1	21.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	0	13	4	2	5
30	Bedroom1	Centurion	3.5	2.45	11.0	1	21.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	160	13	4	2	5
31	Bedroom1	Centurion	3.5	2.45	11.0	1	21.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	0	13	4	2	5
32	Bedroom2	Wingate Park	3.3	2.55	10.8	1	43.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	None	0	137.9	0	6	2	5
33	Bedroom3	Moreleta Park	3.0	2.50	8.4	1	0.0	Y	0.0	Y	23.0	N	0.0	Y	Ordinary	None	0	158.3	0	6	32	5
34	Bathroom	Faerie Glen	2.3	2.64	4.4	1	0.0	Y	20.0	N	33.0	N	0.0	Y	Ordinary	None	0	454.5	0	6	32	5
35	Dormit1	Negev Desert	3.1	2.87	23.0	1	13.6	N	0.0	N	3.4	N	0.0	Y	Ordinary	Heavy	0	0	14	45	13	3
36	Dormit1	Negev Desert	3.1	2.87	23.0	1	13.6	N	0.0	N	3.4	N	0.0	Y	Ordinary	Heavy	0	0	14	45	13	3
37	Dormit1	Negev Desert	3.1	2.87	23.0	1	13.6	N	0.0	N	3.4	N	0.0	Y	Ordinary	Heavy	0	0	14	45	13	3
38	Dormit2	Negev Desert	2.2	2.87	23.0	1	3.4	N	0.0	Y	13.6	N	0.0	N	Ordinary	Heavy	0	0	14	45	13	3
39	Dormit2	Negev Desert	2.2	2.87	23.0	1	3.4	N	0.0	Y	13.6	N	0.0	N	Ordinary	Heavy	0	0	14	45	13	3
40	Dormit2	Negev Desert	2.2	2.87	23.0	1	3.4	N	0.0	Y	13.6	N	0.0	N	Ordinary	Heavy	0	0	14	45	13	3
41	Prefab	Negev Desert	3.5	2.62	13.0	1	14.6	N	0.0	N	14.6	N	0.0	Y	Ordinary	Heavy	0	0	14	54	5	21
42	Prefab	Negev Desert	3.5	2.62	13.0	1	14.6	N	0.0	N	14.6	N	0.0	Y	Ordinary	Heavy	0	0	14	54	5	21
43	Prefab	Negev Desert	3.5	2.62	13.0	1	14.6	N	0.0	N	14.6	N	0.0	Y	Ordinary	Heavy	0	0	14	54	5	21
44	Garage	Centurion	3.2	3.17	18.0	1	0.0	Y	5.3	N	0.0	N	0.0	N	Ordinary	Heavy	0	0	18	4	0	1
45	Garage	Centurion	3.2	3.17	18.0	1	0.0	Y	5.3	N	0.0	N	0.0	N	Ordinary	Heavy	0	166.7	18	4	0	1
46	Shop	Centurion	10.5	2.55	204.0	2	0.0	Y	28.6	N	14.2	N	0.0	Y	Ordinary	Heavy	0	0	43	3	32	2

NO.	BUILDING ZONE	LOCATION	N WALL LENGTH (M)	HEIGHT (M)	FLOOR AREA (M²)	NO. OF STORIES	NORTH GLAZING (%)	I	EAST GLAZING (%)	I	SOUTH GLAZING (%)	I	WEST GLAZING (%)	I	GLASS TYPE	SHADING	PEOPLE	LOADS (W/m²)	AZIMUTH ANGLE (Deg.)	WALL TYPE	ROOF TYPE	FLOOR TYPE
47	Shop	Centurion	10.5	2.55	204.0	2	0.0	Y	28.6	N	14.2	N	0.0	Y	Ordinary	Heavy	0	0	43	3	**32**	2
48	Shop	Centurion	10.5	2.55	204.0	2	0.0	Y	28.6	N	14.2	N	0.0	Y	Ordinary	Heavy	0	34.3	43	3	**32**	2
49	School1	Menlo Park	8.5	3.00	58.0	1	29.7	N	0.0	Y	58.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	**35**	9
50	School1	Menlo Park	8.5	3.00	58.0	1	29.7	N	0.0	Y	58.9	N	0.0	N	Ordinary	Heavy	0	0	0	4	**35**	9
51	School2	The Willows	7.2	2.66	51.5	1	51.7	N	0.0	Y	51.7	N	0.0	Y	Ordinary	Light	0	0	0	54	**29**	21
52	Store1	The Willows	2.9	3.03	12.6	1	0.0	Y	0.0	Y	30.1	N	0.0	N	Ordinary	None	0	115.8	0	54	**2**	5
53	Store2	Volksrust	15.3	4.75	763.0	1	3.8	N	3.8	N	3.8	N	3.8	N	Ordinary	None	0	0	0	49	0	1
54	Studio	Brooklyn	15.5	4.53	340.0	1	17.0	N	11.7	N	100.0	N	46.8	N	Ordinary	None	0	0	0	6	**2**	3
55	Church	Arcadia	11.1	8.00	200.0	1	14.0	N	0.0	N	6.3	N	0.0	N	Double	Light	0	0	0	4	**35**	5
56	Factory	Groenkloof	77.1	13.86	7755.0	1	0.0	N	0.0	N	0.0	N	0.0	N	Ordinary	None	0	0	0	50	1	**5**
57	Office1	CSIR Pretoria	2.4	2.93	14.0	1	55.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Medium	0	0	0	6	16	2
58	Office1	CSIR Pretoria	2.4	2.93	14.0	1	55.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Medium	0	0	0	6	16	2
59	Office2	GH Marais	3.4	2.82	34.4	1	0.0	Y	28.6	N	0.0	Y	0.0	Y	Ordinary	Light	0	0	0	6	10	6
60	Office3	GH Marais	4.8	2.82	17.5	1	17.6	N	26.0	N	0.0	Y	0.0	Y	Ordinary	Light	0	0	0	6	10	6
61	Office3	GH Marais	4.8	2.82	17.5	1	17.6	N	26.0	N	0.0	Y	0.0	Y	Ordinary	Light	0	-57.1	0	6	10	6
62	Office4	GH Marais	2.4	2.83	12.0	1	35.8	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Light	0	0	0	6	10	6
63	Office5	Cent. Gov. Off.	4.6	3.60	28.9	1	0.0	Y	0.0	Y	31.6	N	0.0	Y	Ordinary	Light	1	10.3	0	4	10	6
64	Office6	Liberty Life	4.6	2.74	21.9	1	0.0	Y	0.0	Y	0.0	Y	41.9	N	Ordinary	Heavy	1	13.7	0	4	**11**	6
65	Office7	Poyntons	3.6	2.83	20.5	1	78.6	N	0.0	Y	0.0*	Y	0.0	Y	Ordinary	None	0	0	0	61	10	6
66	Office8	UNISA Pretoria	3.4	2.80	14.3	1	0.0*	Y	0.0*	Y	71.0	N	0.0	Y	Ordinary	Light	0	0	0	61	10	6
67	Office9	Eng. Block	4.0	2.52	18.1	1	0.0	N	0.0	Y	0.0	Y	14.9	N	Ordinary	Heavy	0	119.3	0	43	19	12
68	Office10	Eng. Block	4.1	2.52	21.3	1	0.0	Y	0.0	Y	14.0	N	72.7	N	Ordinary	Heavy	0	102.7	0	43	19	12
69	Office11	JG Strijdom	3.1	2.96	9.8	1	0.0	Y	0.0	Y	0.0	Y	42.0	N	Ordinary	Heavy	0	220.4	0	4	16	9
70	Office12	JG Strijdom	4.2	3.30	13.9	1	0.0	Y	36.0	N	0.0	Y	0.0	Y	Ordinary	Heavy	0	144.3	0	4	16	9
71	Lightweight	Negev Desert	11.9	2.35	45.9	1	8.6	N	0.0	N	24.0	N	0.0	N	Ordinary	Heavy	0	0	0	62	**2**	21

* Indoor glazing areas were not considered

NO.	BUILDING ZONE	LOCATION	N WALL LENGTH (M)	HEIGHT (M)	FLOOR AREA (M²)	NO. OF STORIES	NORTH GLAZING (%)	I	EAST GLAZING (%)	I	SOUTH GLAZING (%)	I	WEST GLAZING (%)	I	GLASS TYPE	SHADING	PEOPLE	LOADS (W/m²)	AZIMUTH ANGLE (Deg.)	WALL TYPE	ROOF TYPE	FLOOR TYPE
72	Heavyweight	Negev Desert	3.0	3.13	9.7	1	8.5	Y	0.0	N	30.4	N	0.0	N	Ordinary	Heavy	0	0	0	**32**	**8**	2
73	Lightweight	Negev Desert	11.9	2.35	45.9	1	8.6	N	0.0	N	24.0	N	0.0	N	Ordinary	Heavy	0	0	0	62	**2**	21
74	Heavyweight	Negev Desert	3.0	3.13	9.7	1	8.5	Y	0.0	N	30.4	N	0.0	N	Ordinary	Heavy	0	0	0	**32**	**8**	2
75	Room 1-91	Pretoria	2.7	2.21	14.6	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	51.5	0	2	14	2
76	Room 1-90	Pretoria	2.6	2.21	14.6	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	81.04	0	2	14	2
77	Room 1-94	Pretoria	6.2	2.21	43.1	1	0.0	N	0.0	Y	0.0	N	0.0	N	Ordinary	Heavy	0	12.75	0	6	14	1
78	Room 1-93	Pretoria	6.1	2.21	33.2	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	44.61	0	6	14	1
79	Room 1-79	Pretoria	2.7	2.21	8.2	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	137.1	0	2	14	2
80	Room 1-80	Pretoria	2.7	2.21	8.2	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	171.1	0	2	14	2
81	Room 1-82	Pretoria	3.3	2.22	9.9	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	21.3	0	2	14	2
82	Room 1-83	Pretoria	3.3	2.21	14.5	1	0.0	N	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	16.5	0	6	14	2
83	Room 1-122	Pretoria	3.4	2.66	31.6	1	0.0	Y	0.0*	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	46.5	0	4	10	2
84	Room 1-123	Pretoria	3.4	2.67	31.6	1	0.0	Y	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	56.4	0	4	10	2
85	Room 1-125	Pretoria	3.4	2.63	8.3	1	0.0	Y	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	0	0	4	10	2
86	Room 1-126	Pretoria	3.4	2.63	8.3	1	0.0	Y	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	100.8	0	4	10	2
87	Room 1-127	Pretoria	3.4	2.63	16.7	1	0.0	Y	0.0	Y	0.0	Y	0.0	Y	Ordinary	Heavy	0	54	0	4	10	2
88	Room 1-141	Pretoria	6.7	4.00	18.8	1	0.0	Y	4.7	N	0.0	Y	0.0	Y	Ordinary	Light	0	76.2	0	4	13	1
89	Room 1-142	Pretoria	6.7	4.00	18.8	1	0.0	Y	4.7	N	0.0	Y	0.0	Y	Ordinary	Light	0	76.2	0	4	13	1
90	Room 1-143	Pretoria	6.7	4.00	21.0	1	0.0	Y	1.8	N	0.0	Y	0.0	Y	Ordinary	Light	0	37.6	0	4	13	1
91	Room 1-145	Pretoria	6.7	4.00	35.5	1	0.0	Y	1.2	N	2.9	N	0.0	Y	Ordinary	Light	0	17	0	6	13	1
92	Room 1-9	Pretoria	7.2	3.33	30.5	1	0.0*	Y	13.1	N	7.5	N	13.1	N	Ordinary	Light	0	-2.3	0	6	2	1
93	Room 1-7	Pretoria	5.5	3.31	27.0	1	0.0*	Y	21.5	N	0.0*	Y	0.0	Y	Ordinary	Light	0	43	0	4	2	1
94	Room 1-9	Pretoria	7.2	3.33	30.5	1	0.0*	Y	13.1	N	7.5	N	13.1	N	Ordinary	Light	0	72.9	0	6	2	1
95	Room 1-7	Pretoria	5.5	3.30	27.0	1	0.0*	Y	21.5	N	0*	Y	0.0	Y	Ordinary	Heavy	0	45.5	0	4	2	1
96	Sasol-E	Secunda	26.3	3.09	683.7	1	22.2	N	12.6	N	22.2	N	10	N	Ordinary	None	48	11.1	0	6	**29**	15
97	Sasol-F	Secunda	10.6	5.62	135.7	1	0.0	Y	100.0	N	0	Y	100	N	Ordinary	Medium	5	4.4	0	6	**11**	5
98	Sasol-N	Secunda	36.0	2.81	911.8	1	35.5	N	15.0	N	22.2	N	15	N	Ordinary	Light	48	14.3	0	6	19	5

NO.	BUILDING ZONE	LOCATION	N WALL LENGTH (M)	HEIGHT (M)	FLOOR AREA (M^2)	NO. OF STORIES	NORTH GLAZING (%)	I	EAST GLAZING (%)	I	SOUTH GLAZING (%)	I	WEST GLAZING (%)	I	GLASS TYPE	SHADING	PEOPLE	LOADS (W/m^2)	AZIMUTH ANGLE (Deg.)	WALL TYPE	ROOF TYPE	FLOOR TYPE
99	Sasol-N	Secunda	33.0	3.07	911.8	1	35.5	N	15.0	N	22.2	N	15	N	Ordinary	Light	48	11	0	6	**29**	15
100	Sasol-S	Secunda	30.6	2.81	789.2	1	19.5	N	6.0	N	17.5	N	15.5	N	Ordinary	Light	24	15.2	0	6	19	5
101	Sasol-S	Secunda	28.8	3.07	911.8	1	21.6	N	20.2	N	22.2	N	15.1	N	Ordinary	Light	44	12.7	0	6	**29**	15
102	Sasol-W	Secunda	28.8	2.82	683.9	1	27.8	N	12.6	N	22.2	N	5	N	Ordinary	Light	27	13.2	0	6	19	5
103	Sasol-W	Secunda	32.8	3.09	683.9	1	22.2	N	12.6	N	22.2	N	5	N	Ordinary	Light	18	17.5	0	6	**29**	15

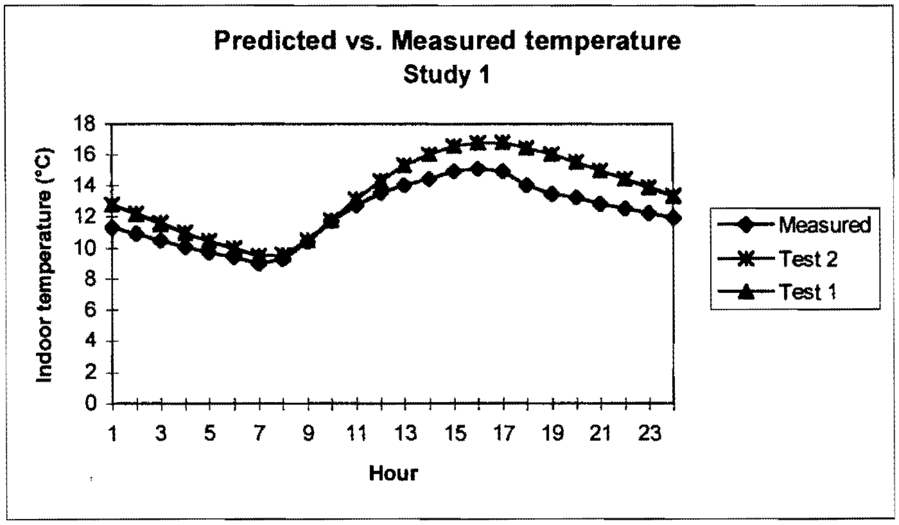
Table B. 1 - Summary of the design tool input requirements.

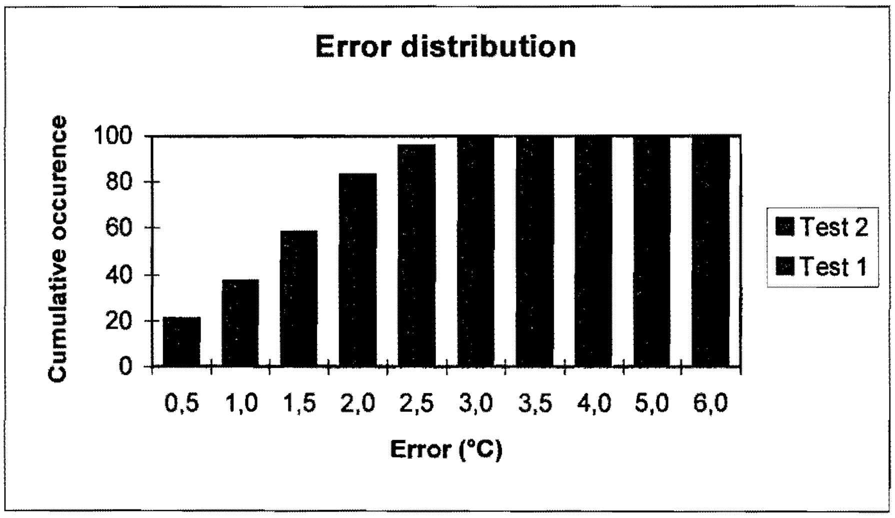
Appendix C

VERIFICATION RESULT

STUDY 1

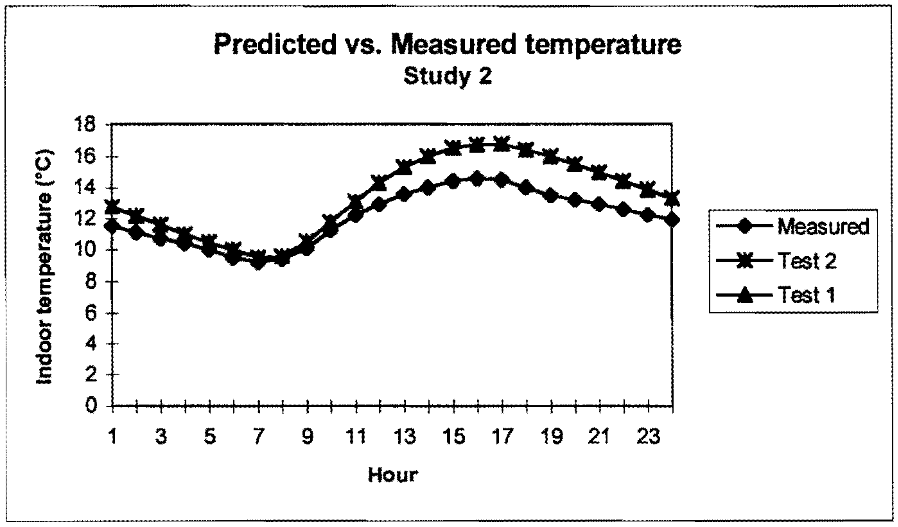
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	11.3	12.7	12.7	13	14.0	15.3	15.3
2	10.9	12.2	12.1	14	14.4	16.0	16.0
3	10.5	11.6	11.6	15	14.9	16.6	16.6
4	10.1	11.0	11.0	16	15.1	16.8	16.8
5	9.7	10.5	10.5	17	14.9	16.8	16.8
6	9.4	10.0	10.0	18	14.0	16.4	16.4
7	9.0	9.5	9.5	19	13.4	16.0	16.0
8	9.3	9.6	9.6	20	13.2	15.5	15.5
9	10.4	10.5	10.5	21	12.8	15.0	15.0
10	11.7	11.8	11.8	22	12.5	14.4	14.4
11	12.7	13.1	13.1	23	12.2	13.9	13.9
12	13.5	14.3	14.3	24	11.9	13.3	13.3

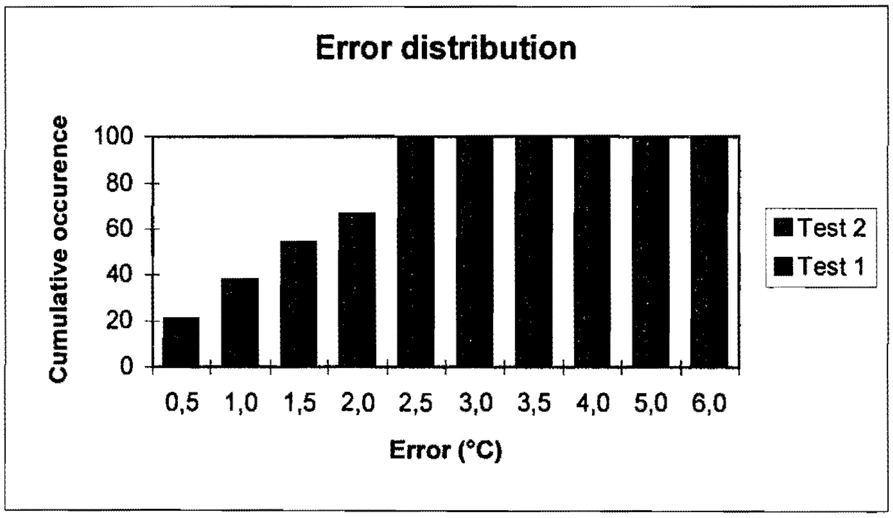




STUDY 2

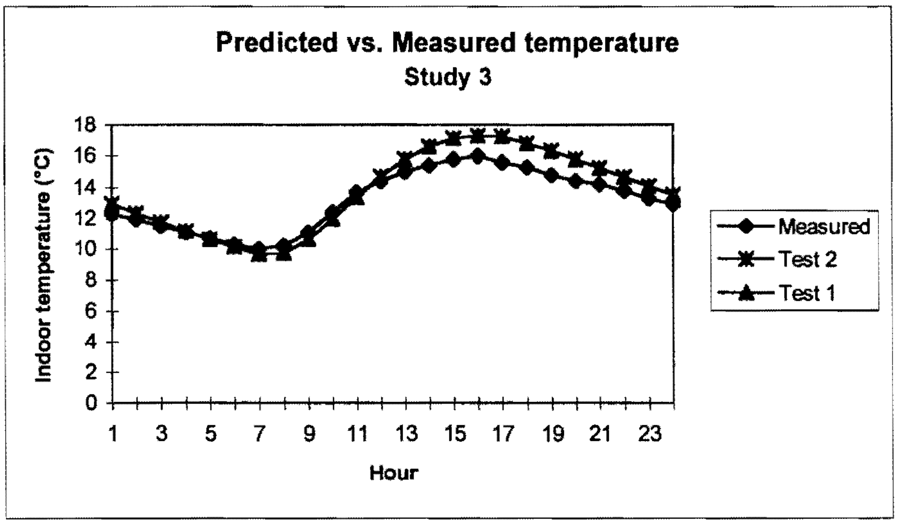
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	11.5	12.7	12.7	13	13.6	15.3	15.3
2	11.1	12.2	12.1	14	14.0	16.0	16.0
3	10.7	11.6	11.6	15	14.4	16.6	16.6
4	10.4	11.0	11.0	16	14.6	16.8	16.8
5	10.0	10.5	10.5	17	14.5	16.8	16.8
6	9.5	10.0	10.0	18	14.0	16.4	16.4
7	9.2	9.5	9.5	19	13.5	16.0	16.0
8	9.4	9.6	9.6	20	13.2	15.5	15.5
9	10.1	10.5	10.5	21	12.9	15.0	15.0
10	11.2	11.8	11.8	22	12.6	14.4	14.4
11	12.2	13.1	13.1	23	12.2	13.9	13.9
12	12.9	14.3	14.3	24	11.9	13.3	13.3

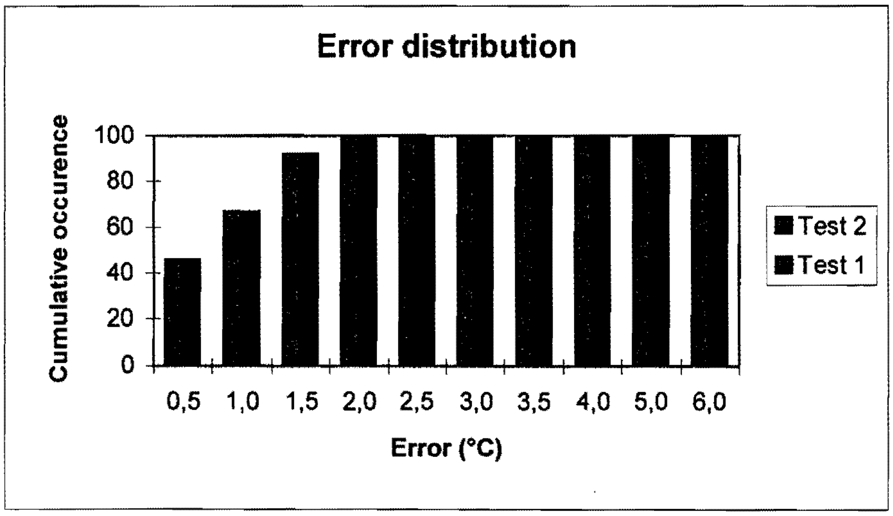




STUDY 3

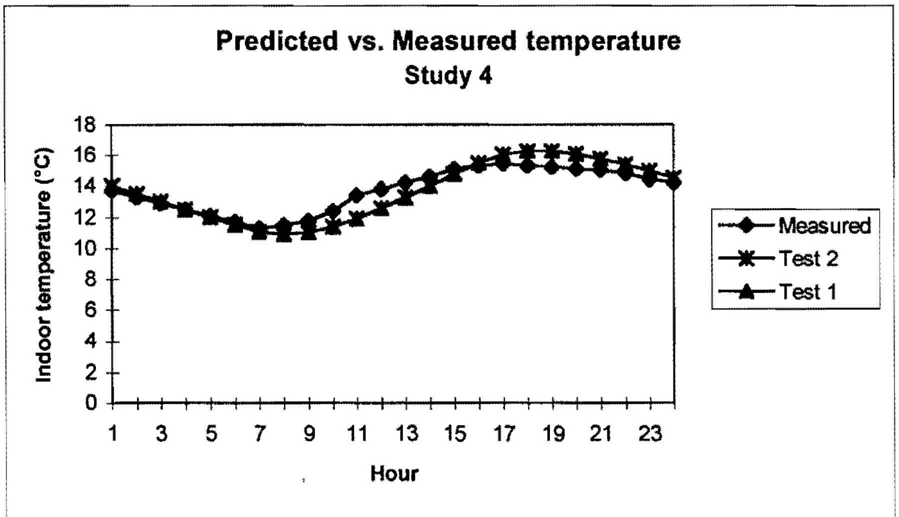
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	12.3	13.0	12.9	13	15.0	15.8	15.8
2	11.9	12.4	12.4	14	15.4	16.6	16.6
3	11.5	11.8	11.8	15	15.8	17.1	17.1
4	11.1	11.2	11.2	16	16.0	17.3	17.3
5	10.7	10.6	10.6	17	15.6	17.2	17.2
6	10.3	10.1	10.2	18	15.3	16.8	16.8
7	10.0	9.6	9.7	19	14.8	16.3	16.3
8	10.2	9.7	9.7	20	14.4	15.8	15.8
9	11.1	10.6	10.6	21	14.2	15.2	15.2
10	12.4	12.0	12.0	22	13.8	14.7	14.7
11	13.7	13.4	13.4	23	13.3	14.1	14.1
12	14.4	14.7	14.7	24	12.9	13.5	13.5

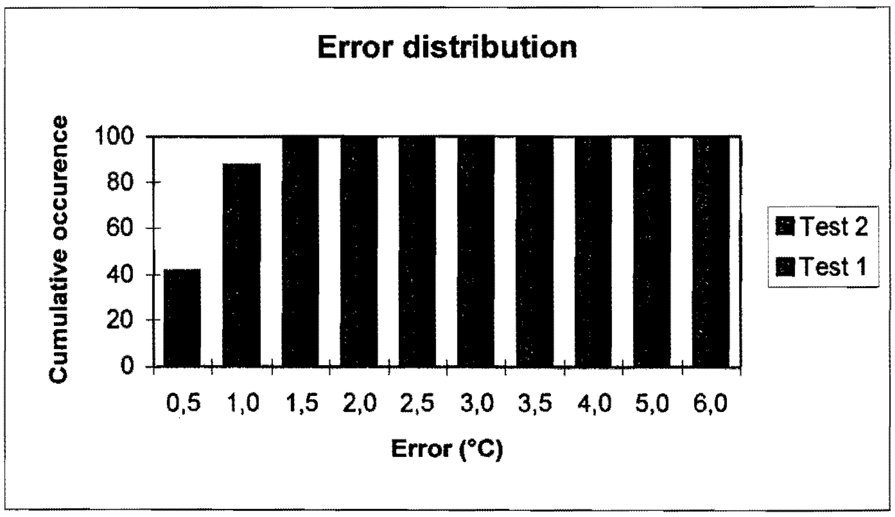




STUDY 4

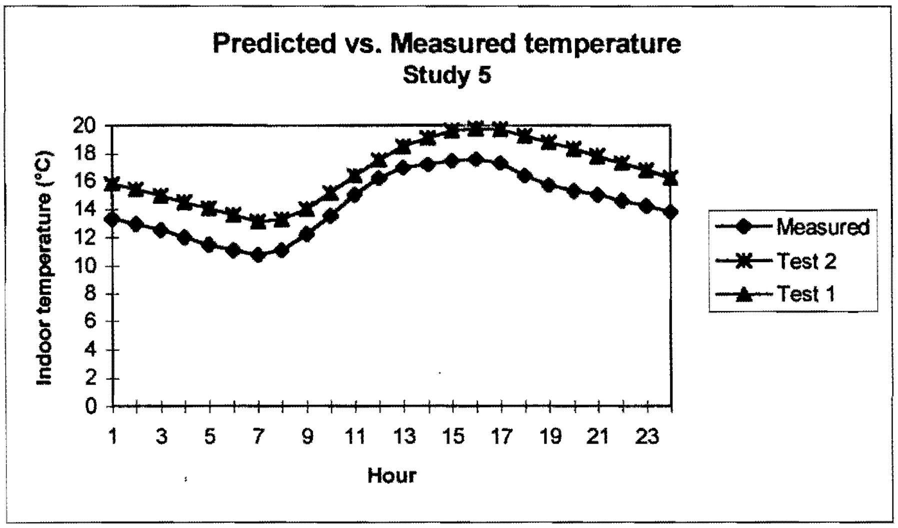
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	13.7	14.0	14.0	13	14.2	13.3	13.3
2	13.3	13.5	13.5	14	14.6	14.0	14.0
3	12.9	13.0	13.0	15	15.1	14.8	14.8
4	12.5	12.5	12.5	16	15.3	15.5	15.4
5	12.1	12.0	12.0	17	15.4	16.1	16.0
6	11.7	11.6	11.6	18	15.3	16.2	16.2
7	11.3	11.1	11.1	19	15.2	16.2	16.2
8	11.5	10.9	10.9	20	15.1	16.1	16.1
9	11.8	11.1	11.1	21	15.0	15.8	15.8
10	12.4	11.4	11.4	22	14.8	15.4	15.4
11	13.4	11.9	11.9	23	14.4	15.0	14.9
12	13.8	12.6	12.6	24	14.2	14.5	14.5

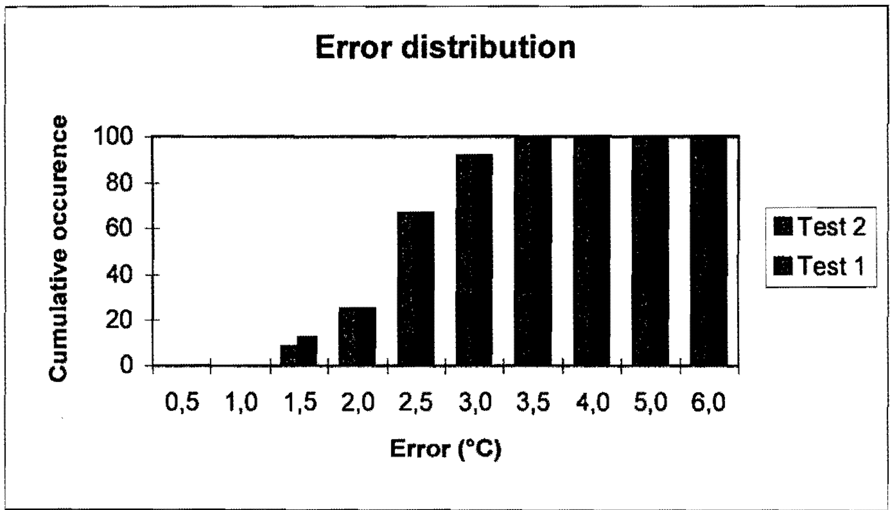




STUDY 5

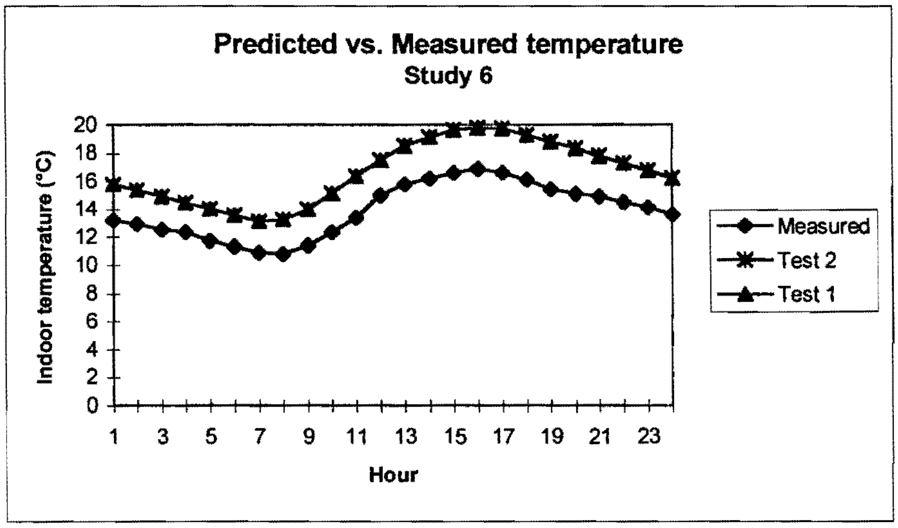
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	13.3	15.8	15.8	13	17.0	18.5	18.5
2	12.9	15.4	15.4	14	17.2	19.1	19.1
3	12.5	14.9	14.9	15	17.5	19.6	19.6
4	12.0	14.4	14.4	16	17.6	19.8	19.8
5	11.5	14.0	14.0	17	17.3	19.7	19.7
6	11.1	13.6	13.6	18	16.4	19.3	19.2
7	10.8	13.1	13.1	19	15.7	18.8	18.8
8	11.1	13.2	13.2	20	15.3	18.4	18.3
9	12.2	14.0	14.0	21	15.0	17.8	17.8
10	13.5	15.2	15.1	22	14.6	17.3	17.3
11	15.0	16.4	16.4	23	14.2	16.8	16.8
12	16.2	17.6	17.6	24	13.8	16.2	16.2

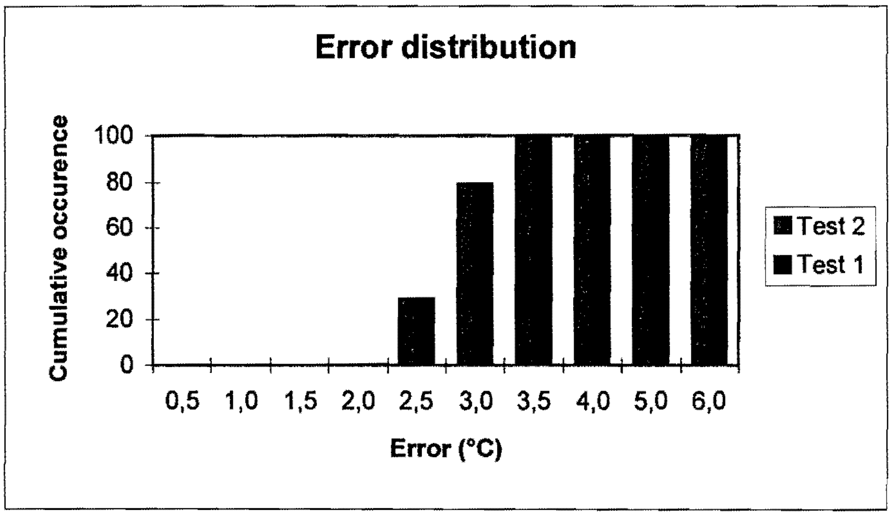




STUDY 6

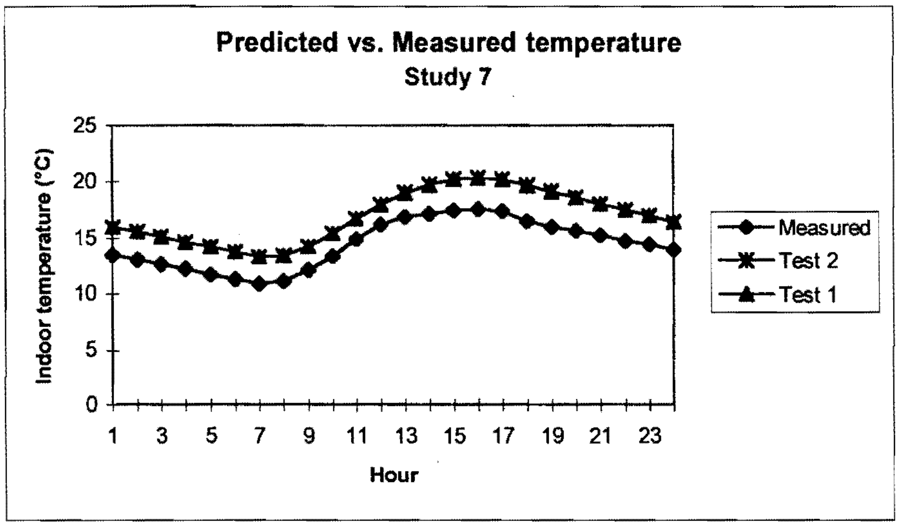
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	13.2	15.8	15.8	13	15.8	18.5	18.5
2	12.9	15.4	15.4	14	16.2	19.1	19.1
3	12.5	14.9	14.9	15	16.6	19.6	19.6
4	12.3	14.4	14.4	16	16.9	19.8	19.8
5	11.7	14.0	14.0	17	16.6	19.7	19.7
6	11.3	13.6	13.6	18	16.1	19.3	19.2
7	10.9	13.1	13.1	19	15.4	18.8	18.8
8	10.8	13.2	13.2	20	15.1	18.4	18.3
9	11.4	14.0	14.0	21	14.9	17.8	17.8
10	12.3	15.2	15.1	22	14.5	17.3	17.3
11	13.4	16.4	16.4	23	14.1	16.8	16.8
12	15.0	17.6	17.6	24	13.6	16.2	16.2

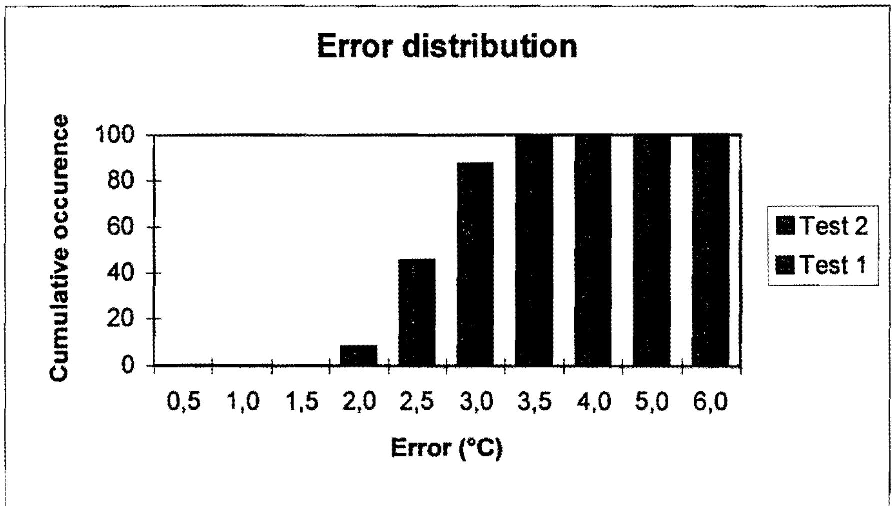




STUDY 7

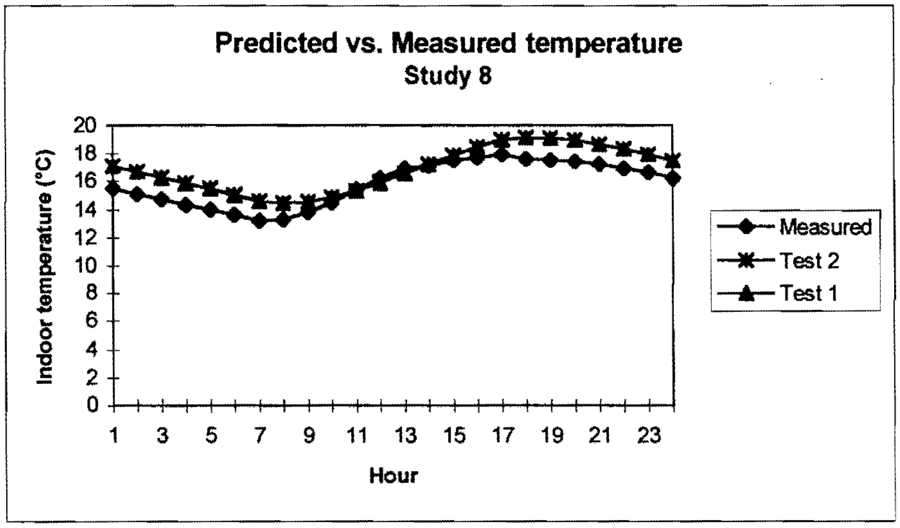
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	13.4	16.0	16.0	13	16.9	19.1	19.1
2	13.0	15.5	15.5	14	17.2	19.7	19.7
3	12.6	15.1	15.1	15	17.5	20.2	20.2
4	12.2	14.6	14.6	16	17.6	20.3	20.3
5	11.7	14.2	14.2	17	17.4	20.2	20.2
6	11.3	13.7	13.7	18	16.5	19.7	19.7
7	10.9	13.3	13.3	19	16.0	19.2	19.1
8	11.1	13.4	13.4	20	15.6	18.6	18.6
9	12.1	14.2	14.2	21	15.2	18.1	18.1
10	13.3	15.4	15.4	22	14.7	17.6	17.6
11	14.9	16.7	16.7	23	14.4	17.0	17.0
12	16.2	18.0	18.0	24	13.9	16.5	16.4

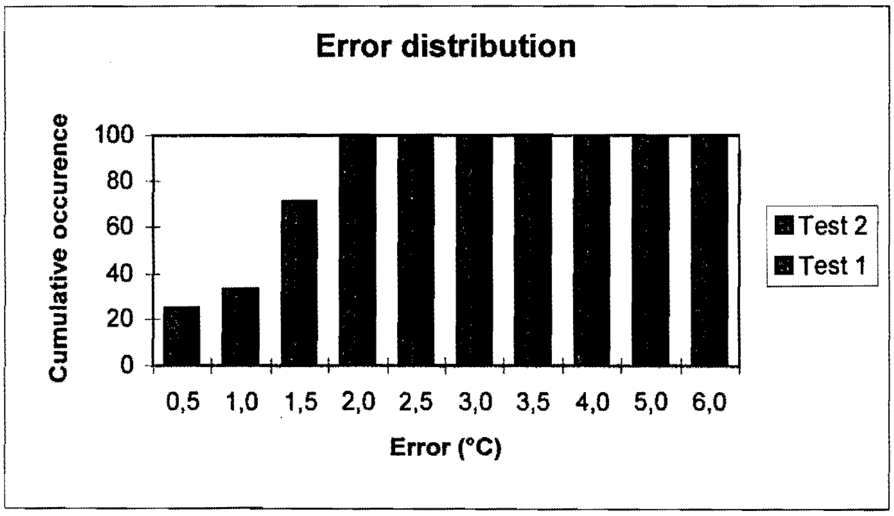




STUDY 8

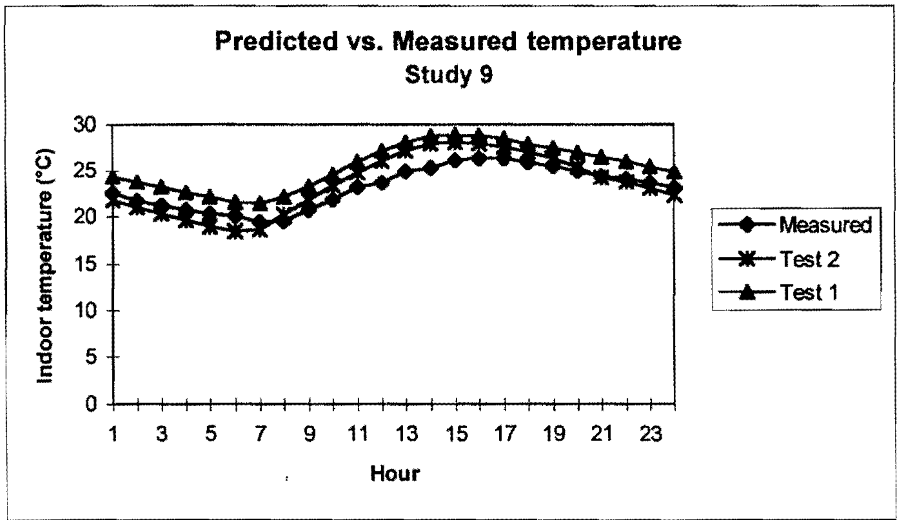
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	15.5	17.1	17.1	13	16.9	16.6	16.5
2	15.1	16.7	16.7	14	17.1	17.2	17.2
3	14.7	16.2	16.3	15	17.5	17.9	17.9
4	14.3	15.8	15.8	16	17.7	18.5	18.5
5	14.0	15.4	15.4	17	17.9	19.0	19.0
6	13.6	15.0	15.0	18	17.6	19.2	19.2
7	13.2	14.6	14.6	19	17.5	19.1	19.1
8	13.3	14.5	14.5	20	17.4	19.0	19.0
9	13.8	14.5	14.5	21	17.2	18.7	18.7
10	14.5	14.8	14.8	22	16.9	18.3	18.3
11	15.4	15.3	15.3	23	16.6	17.9	17.9
12	16.2	15.9	15.9	24	16.2	17.5	17.5

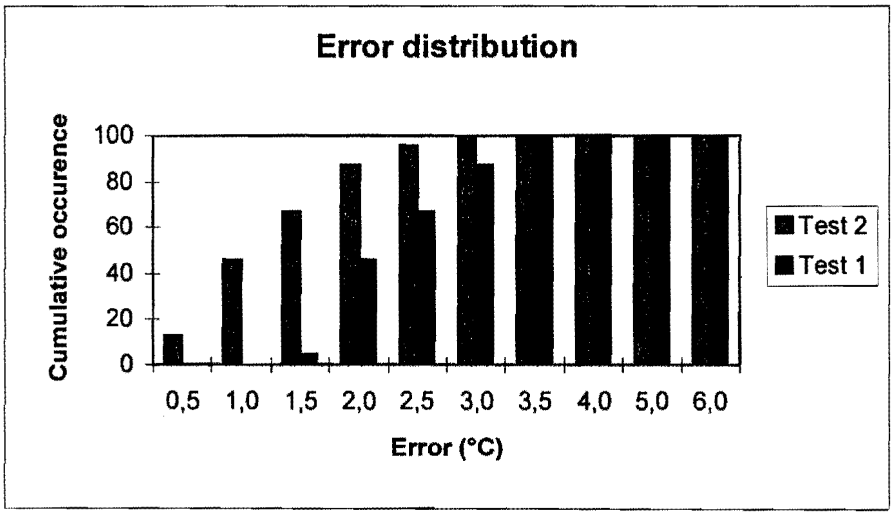




STUDY 9

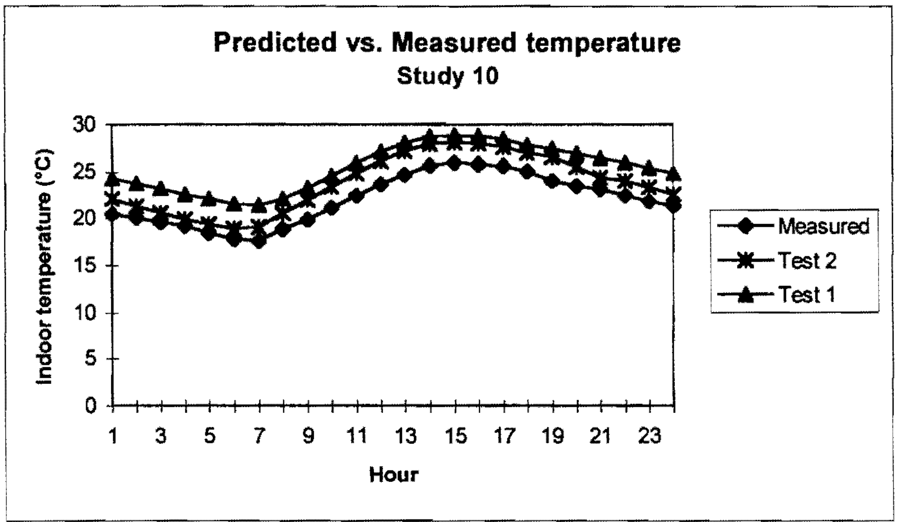
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.6	21.7	24.3	13	24.9	27.1	28.1
2	21.7	21.0	23.7	14	25.3	27.9	28.7
3	21.2	20.3	23.2	15	26.1	28.0	28.9
4	20.7	19.6	22.6	16	26.3	27.9	28.8
5	20.3	19.0	22.1	17	26.3	27.6	28.5
6	20.1	18.5	21.5	18	25.9	27.0	27.8
7	19.4	18.7	21.4	19	25.5	26.3	27.4
8	19.5	20.2	22.1	20	24.9	25.3	26.9
9	20.7	21.8	23.2	21	24.4	24.2	26.5
10	21.8	23.3	24.6	22	24.1	23.8	26.0
11	23.2	24.8	26.0	23	23.7	23.0	25.4
12	23.7	26.1	27.2	24	23.1	22.3	24.8

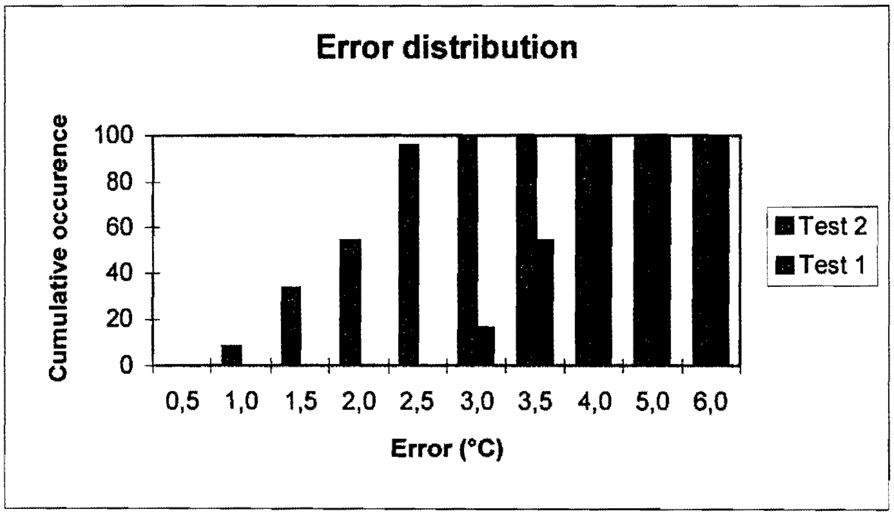




STUDY 10

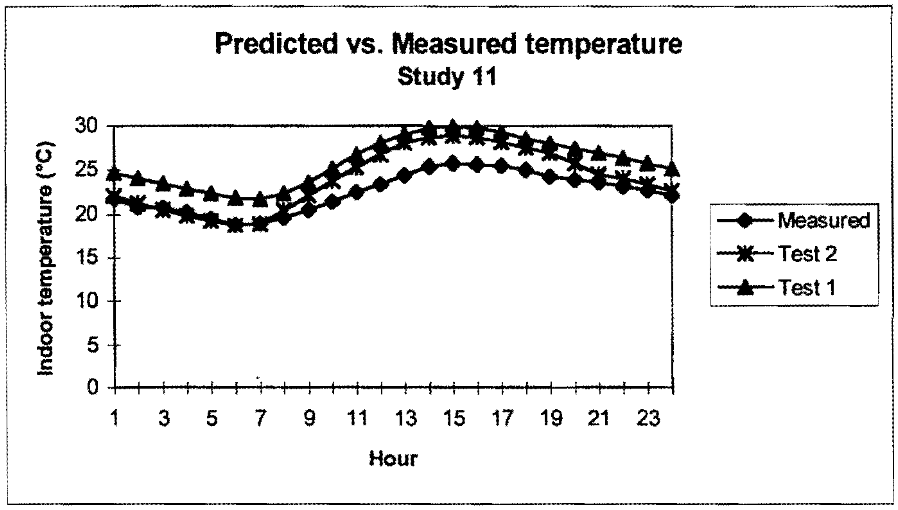
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	20.4	22.1	24.3	13	24.7	27.2	28.1
2	20.0	21.3	23.7	14	25.7	28.0	28.7
3	19.5	20.6	23.2	15	26.0	28.1	28.9
4	19.2	19.9	22.6	16	25.8	28.0	28.8
5	18.4	19.3	22.1	17	25.6	27.6	28.5
6	17.8	18.8	21.5	18	25.1	27.0	27.8
7	17.6	19.0	21.4	19	24.0	26.6	27.4
8	18.8	20.5	22.1	20	23.5	25.6	26.9
9	19.8	21.9	23.2	21	23.1	24.4	26.5
10	21.1	23.4	24.6	22	22.4	24.0	26.0
11	22.4	24.9	26.0	23	21.8	23.3	25.4
12	23.7	26.2	27.2	24	21.3	22.6	24.8

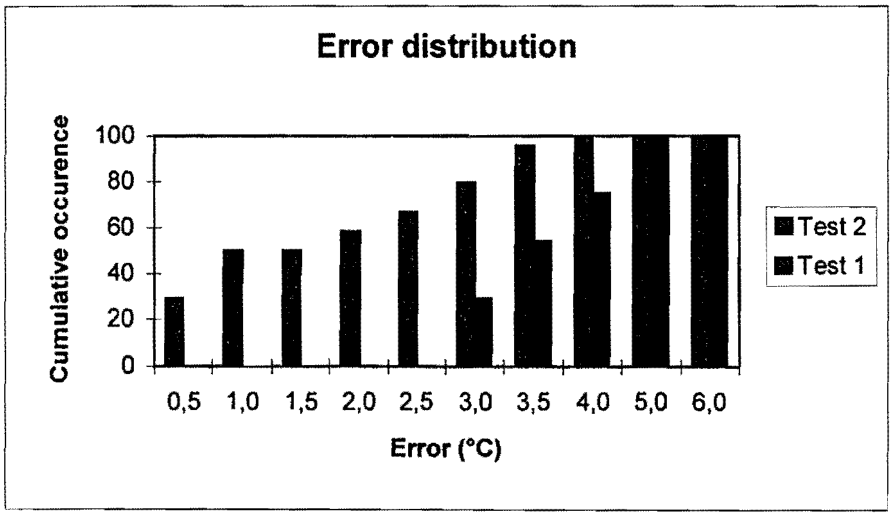




STUDY 11

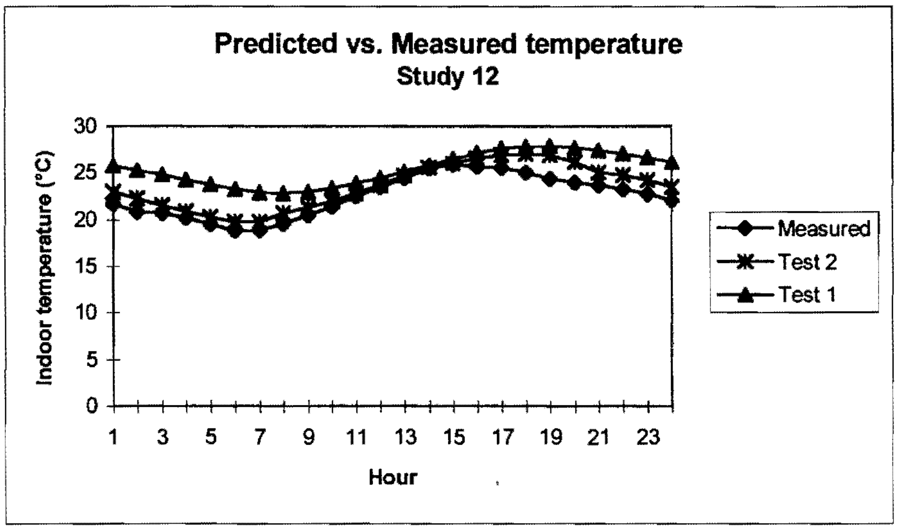
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.7	22.0	24.6	13	24.4	28.0	29.1
2	20.8	21.3	24.1	14	25.4	28.7	29.8
3	20.7	20.5	23.5	15	25.8	28.9	29.9
4	20.2	19.8	22.9	16	25.6	28.6	29.8
5	19.5	19.2	22.3	17	25.5	28.2	29.3
6	18.8	18.7	21.8	18	25.0	27.5	28.5
7	18.9	18.9	21.7	19	24.3	26.9	28.0
8	19.6	20.4	22.3	20	23.9	25.8	27.4
9	20.5	22.1	23.6	21	23.6	24.5	26.9
10	21.4	23.7	25.2	22	23.2	24.1	26.4
11	22.5	25.3	26.7	23	22.7	23.4	25.8
12	23.4	26.7	28.1	24	22.1	22.6	25.2

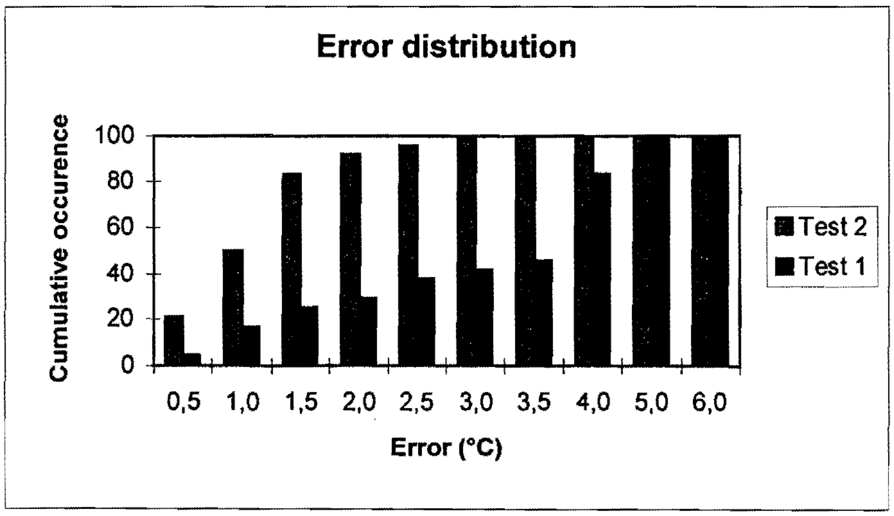




STUDY 12

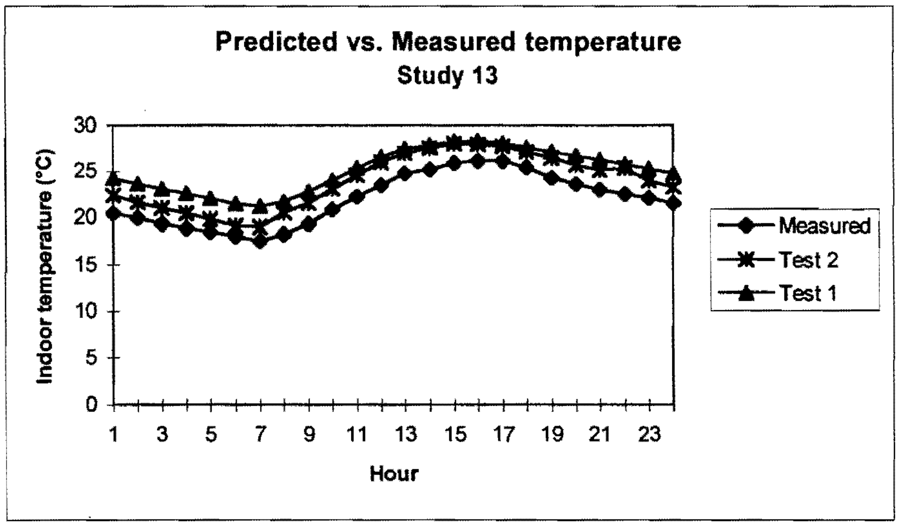
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.7	22.9	25.7	13	24.4	24.6	25.1
2	20.8	22.2	25.2	14	25.4	25.5	25.8
3	20.7	21.5	24.7	15	25.8	26.0	26.4
4	20.2	20.9	24.2	16	25.6	26.5	27.1
5	19.5	20.3	23.7	17	25.5	26.9	27.6
6	18.8	19.8	23.2	18	25.0	27.0	27.8
7	18.9	19.8	22.9	19	24.3	26.9	27.8
8	19.6	20.7	22.8	20	23.9	26.1	27.7
9	20.5	21.3	23.0	21	23.6	25.0	27.4
10	21.4	22.0	23.3	22	23.2	24.8	27.0
11	22.5	22.8	23.8	23	22.7	24.1	26.6
12	23.4	23.6	24.4	24	22.1	23.5	26.1

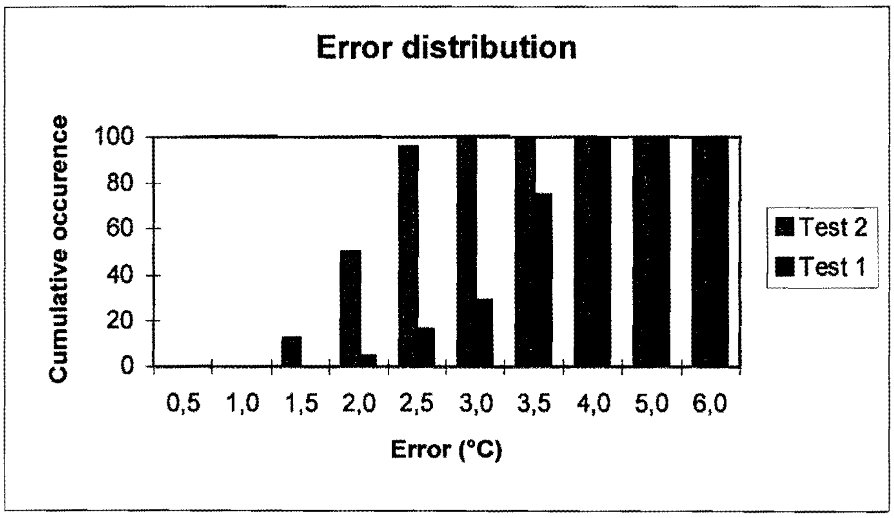




STUDY 13

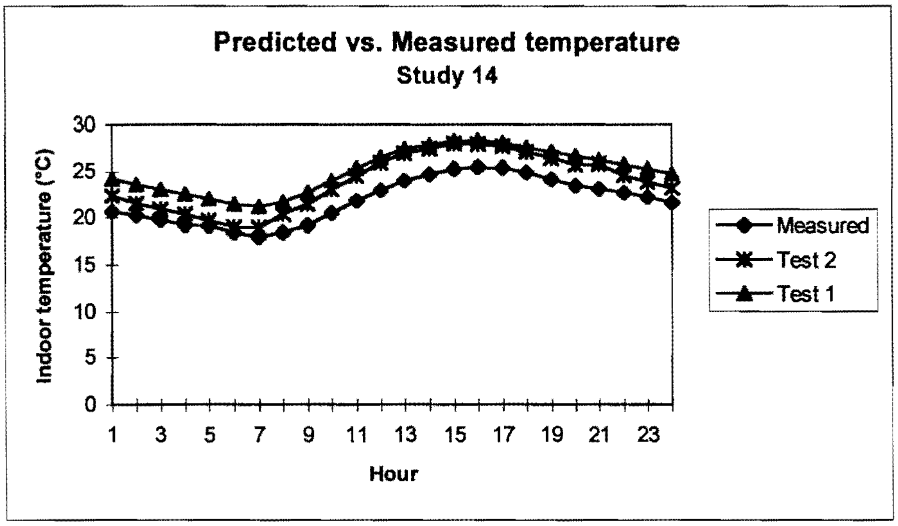
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	20.4	22.4	24.2	13	24.8	27.0	27.4
2	19.9	21.6	23.6	14	25.2	27.5	27.9
3	19.3	21.0	23.1	15	25.9	28.0	28.3
4	18.8	20.4	22.6	16	26.1	27.9	28.3
5	18.5	19.8	22.0	17	26.1	27.7	28.1
6	18.0	19.1	21.5	18	25.4	27.1	27.5
7	17.5	19.0	21.2	19	24.3	26.5	27.1
8	18.2	20.5	21.7	20	23.6	25.7	26.7
9	19.3	21.5	22.8	21	23.0	25.1	26.2
10	20.8	23.1	24.1	22	22.5	25.3	25.8
11	22.2	24.6	25.3	23	22.1	24.0	25.3
12	23.5	26.0	26.5	24	21.5	23.2	24.8

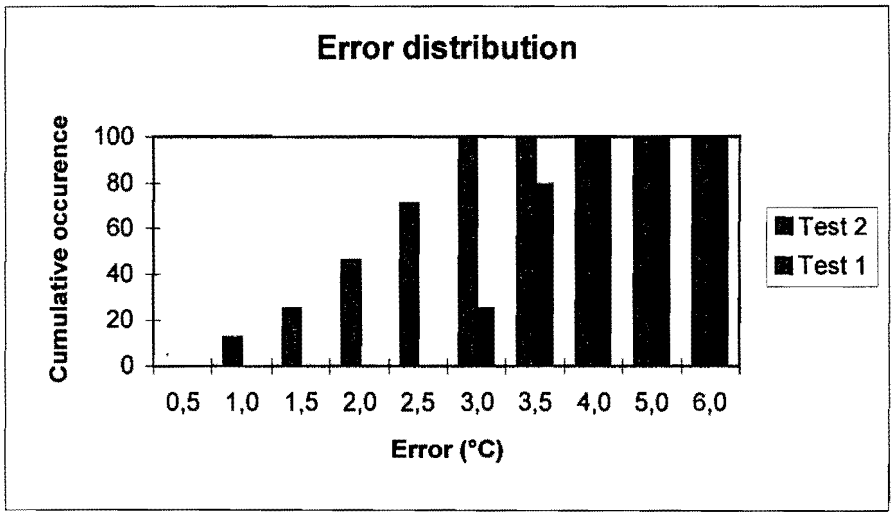




STUDY 14

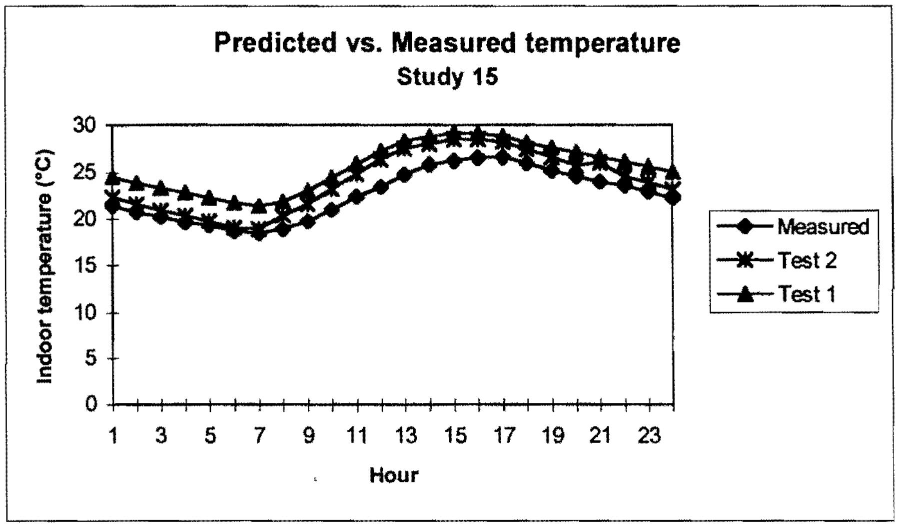
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	20.6	22.4	24.2	13	24.0	27.0	27.4
2	20.2	21.6	23.6	14	24.7	27.5	27.9
3	19.7	20.9	23.1	15	25.3	28.0	28.3
4	19.2	20.4	22.6	16	25.5	27.9	28.3
5	19.1	19.7	22.0	17	25.4	27.7	28.1
6	18.4	19.0	21.5	18	24.9	27.1	27.5
7	17.9	18.9	21.2	19	24.2	26.5	27.1
8	18.4	20.4	21.7	20	23.5	25.7	26.7
9	19.2	21.5	22.8	21	23.1	25.8	26.2
10	20.5	23.1	24.1	22	22.7	24.6	25.8
11	21.8	24.5	25.3	23	22.2	23.9	25.3
12	23.0	25.9	26.5	24	21.6	23.2	24.8

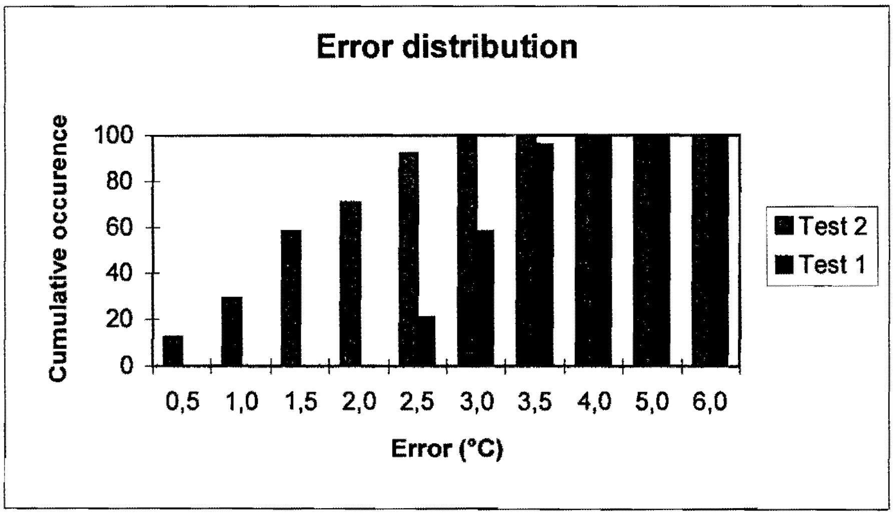




STUDY 15

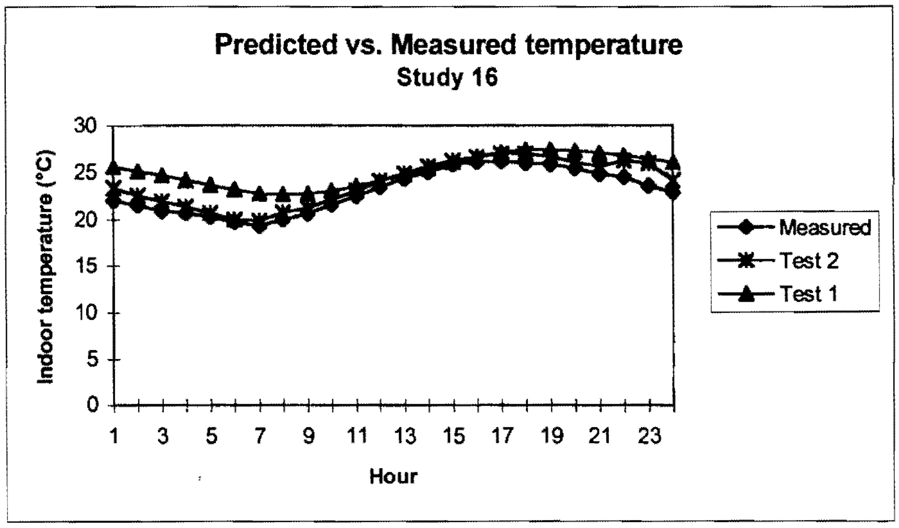
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.4	22.3	24.5	13	24.8	27.5	28.3
2	20.7	21.6	23.9	14	25.8	28.0	28.8
3	20.2	20.9	23.4	15	26.2	28.5	29.2
4	19.6	20.4	22.8	16	26.5	28.5	29.1
5	19.3	19.7	22.3	17	26.6	28.2	28.8
6	18.7	19.0	21.7	18	26.0	27.5	28.1
7	18.5	18.9	21.4	19	25.2	26.6	27.6
8	18.9	20.3	21.9	20	24.6	25.8	27.1
9	19.7	21.6	23.0	21	24.0	26.0	26.6
10	21.0	23.3	24.5	22	23.6	24.6	26.1
11	22.4	24.9	25.9	23	22.9	23.9	25.6
12	23.5	26.4	27.2	24	22.2	23.2	25.1

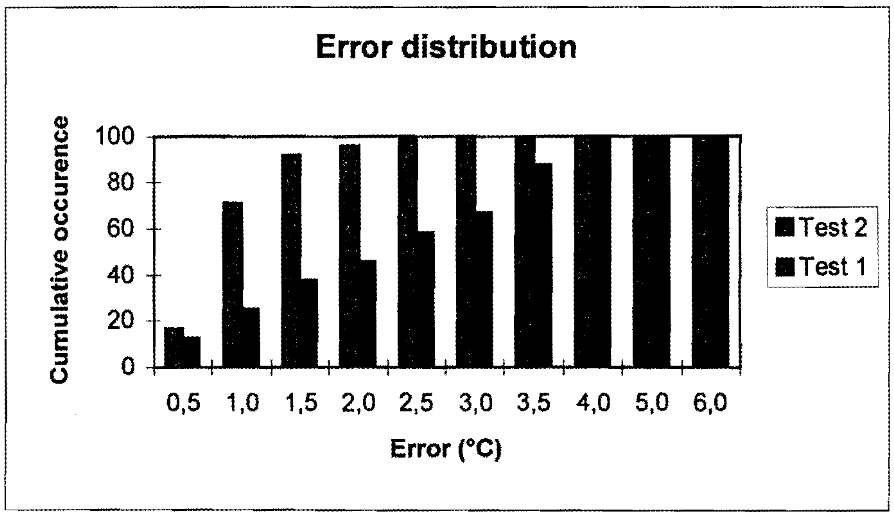




STUDY 16

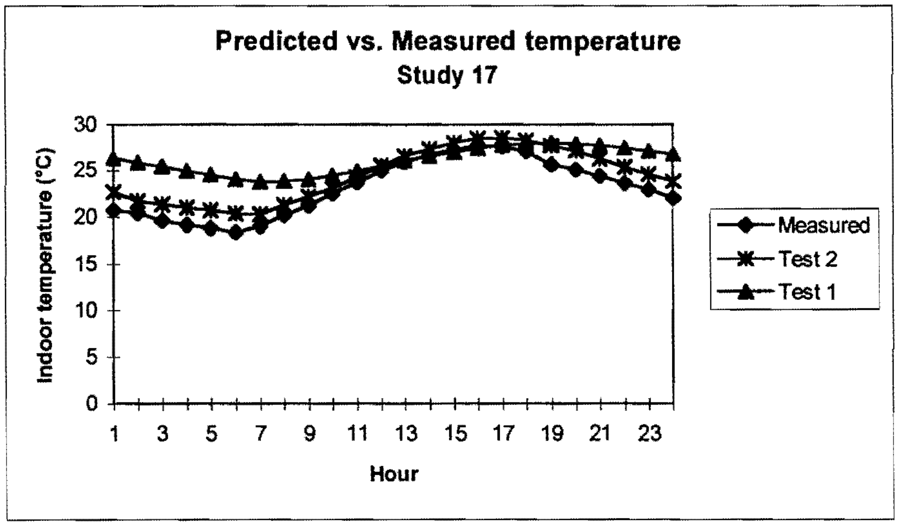
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.0	23.3	25.6	13	24.4	24.8	24.7
2	21.5	22.6	25.1	14	25.0	25.6	25.4
3	20.9	21.9	24.6	15	25.8	26.3	26.0
4	20.7	21.4	24.2	16	26.1	26.6	26.6
5	20.3	20.7	23.7	17	26.2	27.0	27.2
6	19.7	20.0	23.2	18	26.0	27.0	27.4
7	19.3	19.8	22.8	19	25.8	26.7	27.5
8	20.0	20.8	22.7	20	25.4	26.1	27.3
9	20.6	21.3	22.8	21	24.8	25.6	27.1
10	21.6	22.2	23.1	22	24.5	26.3	26.8
11	22.5	23.1	23.5	23	23.6	26.0	26.4
12	23.5	24.1	24.1	24	22.9	24.2	26.0

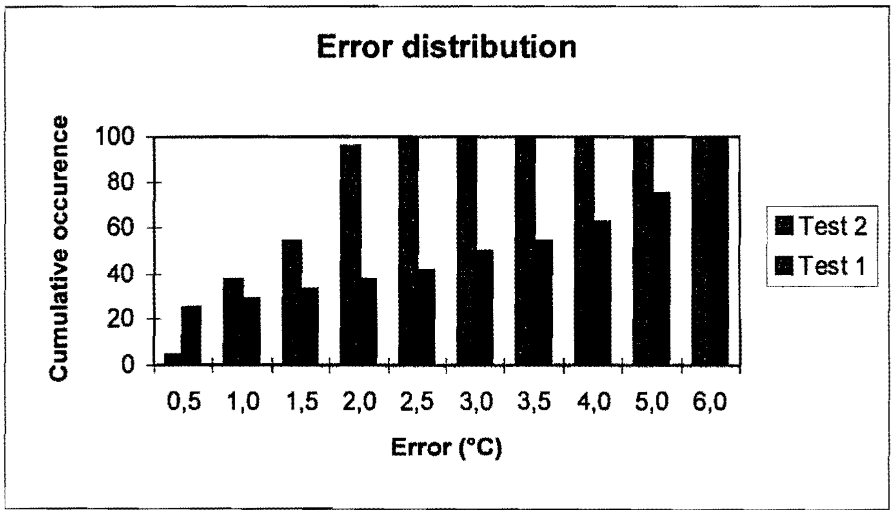




STUDY 17

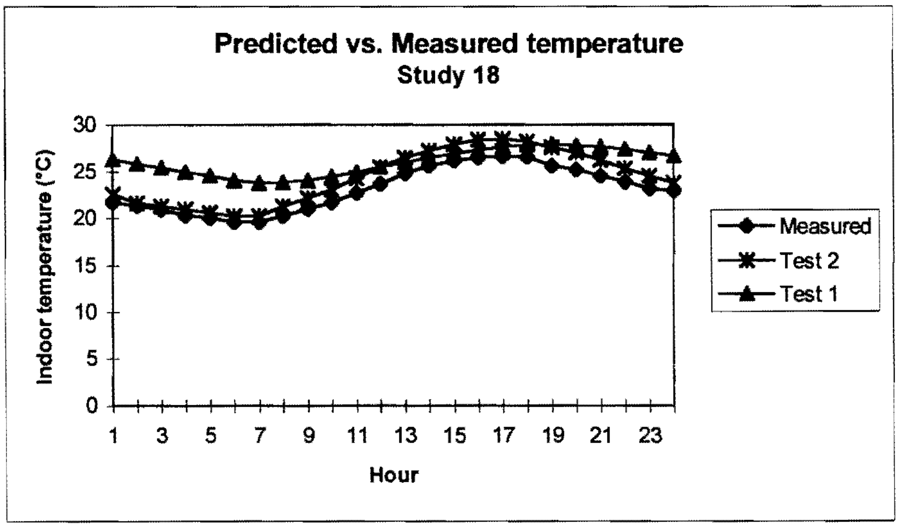
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	20.7	22.6	26.3	13	25.9	26.5	26.0
2	20.4	21.7	25.9	14	26.7	27.3	26.5
3	19.6	21.3	25.4	15	27.2	28.0	27.0
4	19.2	21.0	24.9	16	27.7	28.5	27.4
5	18.8	20.7	24.5	17	27.6	28.5	27.7
6	18.4	20.3	24.1	18	27.0	28.3	27.9
7	19.0	20.3	23.8	19	25.6	27.6	28.0
8	20.2	21.2	23.8	20	25.1	27.1	27.9
9	21.2	22.2	24.1	21	24.4	26.3	27.7
10	22.5	23.1	24.4	22	23.6	25.3	27.4
11	23.7	24.3	25.0	23	22.9	24.6	27.1
12	25.0	25.5	25.5	24	22.0	23.8	26.7

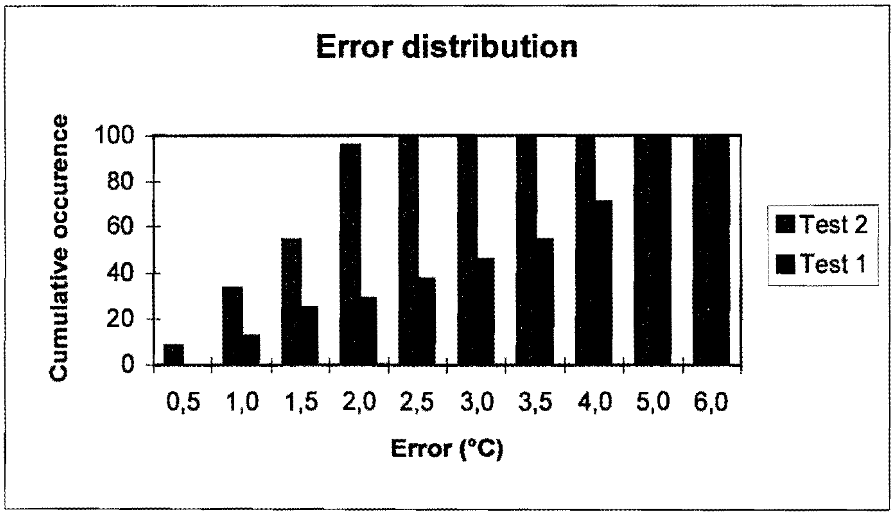




STUDY 18

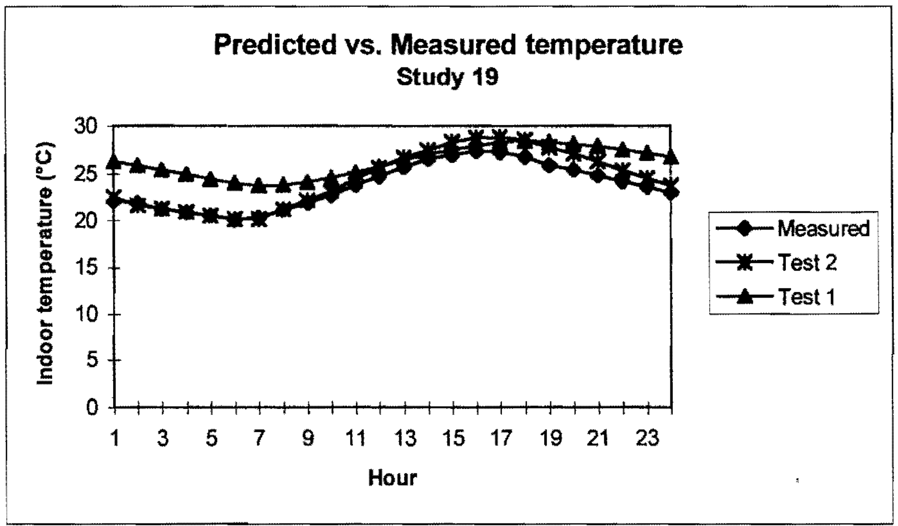
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.7	22.6	26.3	13	24.8	26.5	26.0
2	21.3	21.6	25.9	14	25.6	27.3	26.5
3	20.9	21.3	25.4	15	26.2	28.0	27.0
4	20.3	20.9	24.9	16	26.5	28.5	27.4
5	20.0	20.6	24.5	17	26.7	28.6	27.7
6	19.6	20.2	24.1	18	26.6	28.3	27.9
7	19.6	20.2	23.8	19	25.6	27.6	28.0
8	20.2	21.2	23.8	20	25.2	27.1	27.9
9	21.0	22.1	24.1	21	24.5	26.2	27.7
10	21.7	23.1	24.4	22	23.9	25.3	27.4
11	22.7	24.3	25.0	23	23.2	24.5	27.1
12	23.7	25.5	25.5	24	22.9	23.8	26.7

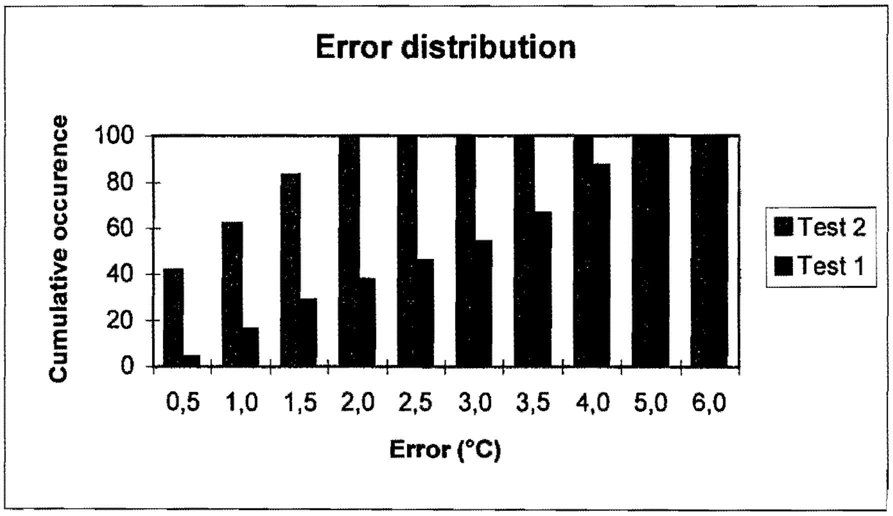




STUDY 19

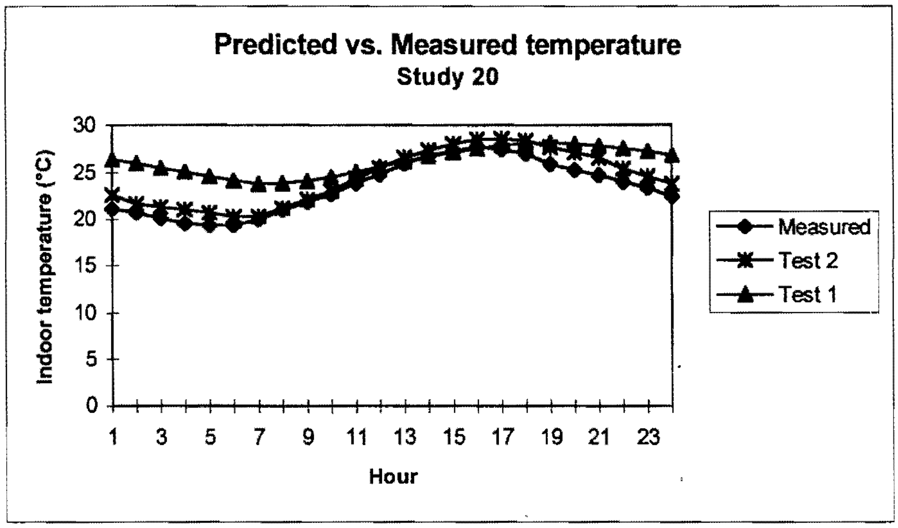
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.1	22.5	26.3	13	25.7	26.7	26.5
2	21.9	21.6	25.9	14	26.6	27.5	27.1
3	21.2	21.2	25.4	15	27.0	28.3	27.6
4	20.8	20.9	24.9	16	27.4	28.8	28.0
5	20.5	20.5	24.5	17	27.3	28.8	28.3
6	20.1	20.2	24.0	18	26.8	28.5	28.5
7	20.3	20.1	23.7	19	25.9	27.8	28.3
8	21.1	21.2	23.8	20	25.4	27.2	28.1
9	21.9	22.2	24.1	21	24.8	26.3	27.9
10	22.7	23.1	24.6	22	24.2	25.3	27.6
11	23.8	24.4	25.2	23	23.6	24.5	27.2
12	24.7	25.6	25.8	24	23.0	23.8	26.8

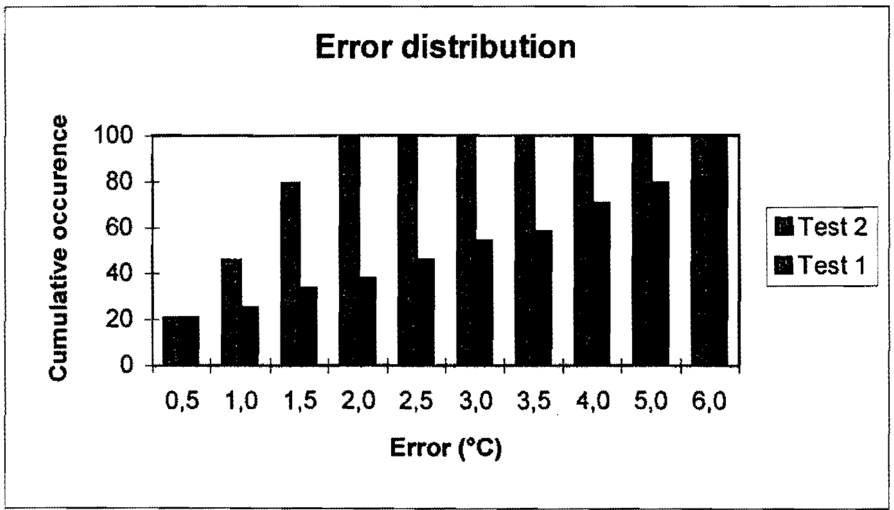




STUDY 20

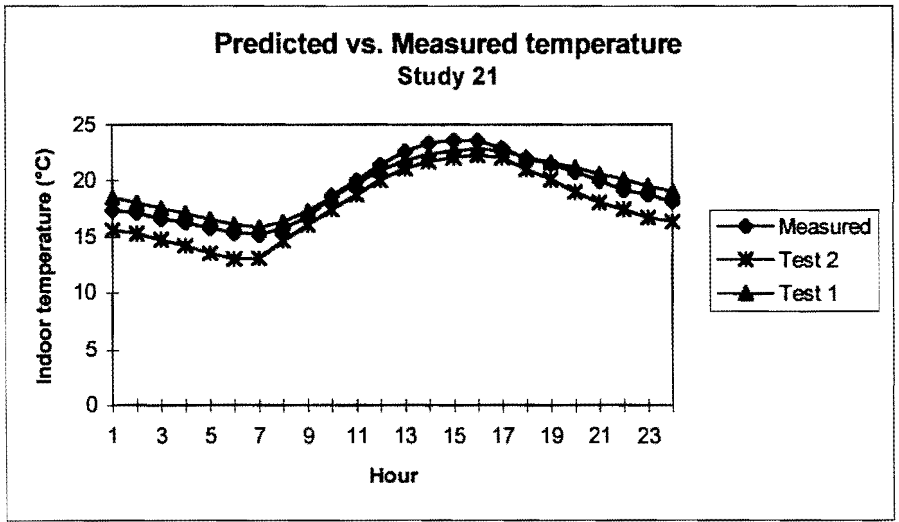
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.1	22.7	26.4	13	26.0	26.6	26.2
2	20.7	21.7	26.0	14	26.8	27.3	26.7
3	20.1	21.3	25.5	15	27.3	28.1	27.2
4	19.5	21.0	25.1	16	27.7	28.6	27.6
5	19.3	20.7	24.6	17	27.5	28.6	27.9
6	19.3	20.3	24.2	18	27.0	28.4	28.2
7	19.9	20.3	23.9	19	25.9	27.7	28.2
8	21.0	21.2	23.9	20	25.3	27.2	28.1
9	21.9	22.2	24.1	21	24.7	26.6	27.9
10	22.7	23.1	24.5	22	24.0	25.4	27.6
11	23.9	24.4	25.1	23	23.4	24.6	27.3
12	24.8	25.5	25.6	24	22.5	23.9	26.9

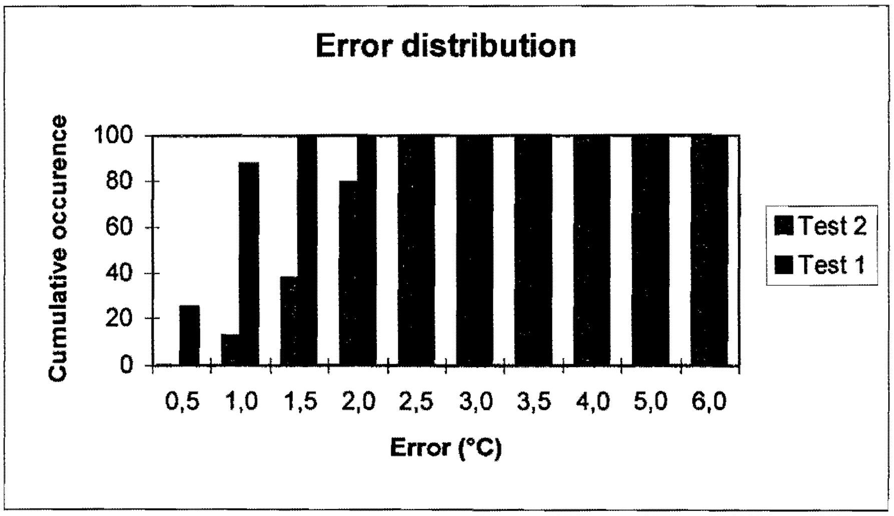




STUDY 21

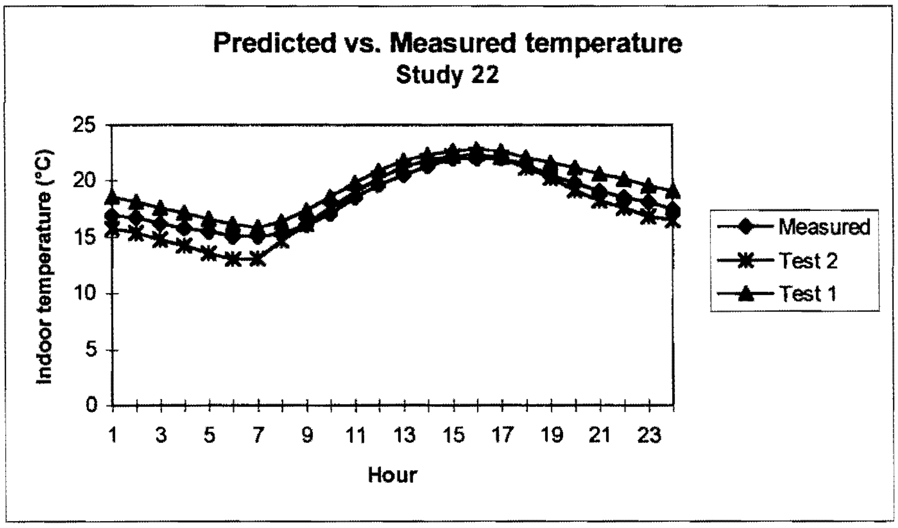
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	17.4	15.6	18.6	13	22.6	21.1	21.8
2	17.2	15.3	18.1	14	23.4	21.7	22.4
3	16.6	14.8	17.6	15	23.6	22.1	22.7
4	16.3	14.2	17.1	16	23.6	22.3	22.9
5	15.8	13.6	16.6	17	22.9	22.0	22.7
6	15.4	13.0	16.1	18	22.0	21.0	22.1
7	15.2	13.1	15.8	19	21.5	20.1	21.7
8	15.8	14.7	16.4	20	20.8	19.0	21.2
9	16.8	16.1	17.4	21	20.0	18.1	20.6
10	18.7	17.5	18.6	22	19.2	17.5	20.1
11	20.0	18.8	19.8	23	18.8	16.7	19.6
12	21.4	20.1	20.9	24	18.2	16.4	19.1

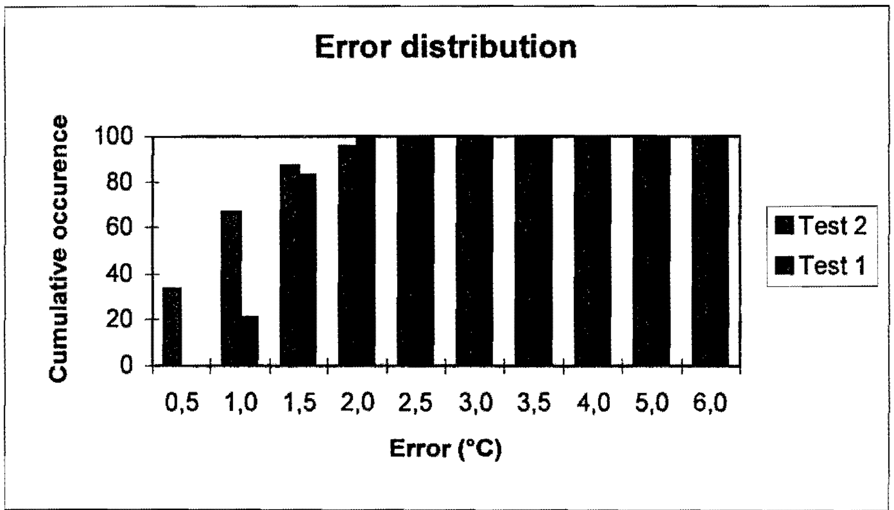




STUDY 22

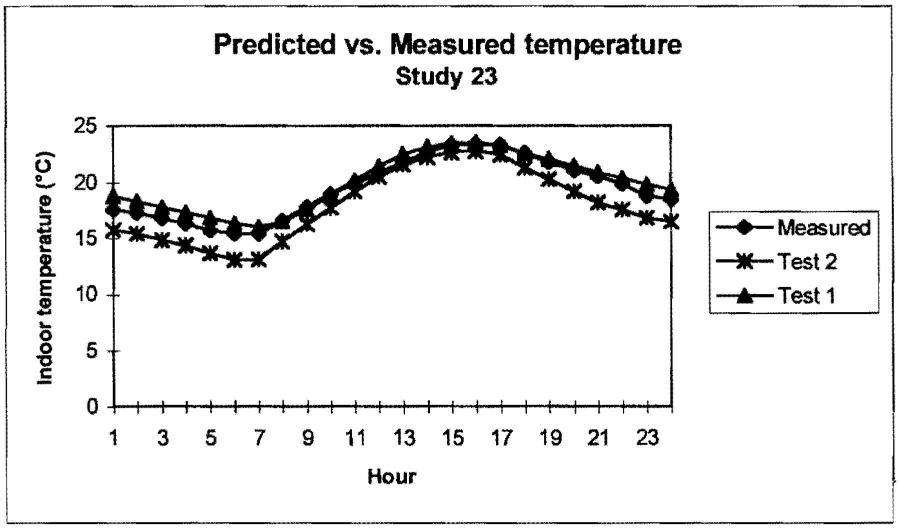
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	16.9	15.7	18.6	13	20.5	21.2	21.8
2	16.7	15.4	18.1	14	21.3	21.8	22.4
3	16.2	14.8	17.6	15	22.0	22.2	22.7
4	15.8	14.3	17.1	16	22.0	22.4	22.9
5	15.5	13.6	16.6	17	22.0	22.1	22.7
6	15.1	13.1	16.1	18	21.5	21.1	22.1
7	15.1	13.1	15.8	19	20.4	20.2	21.7
8	15.3	14.7	16.4	20	19.8	19.2	21.2
9	16.1	16.1	17.4	21	19.1	18.2	20.6
10	17.1	17.6	18.6	22	18.5	17.6	20.1
11	18.5	19.0	19.8	23	18.1	16.9	19.6
12	19.6	20.2	20.9	24	17.5	16.5	19.1

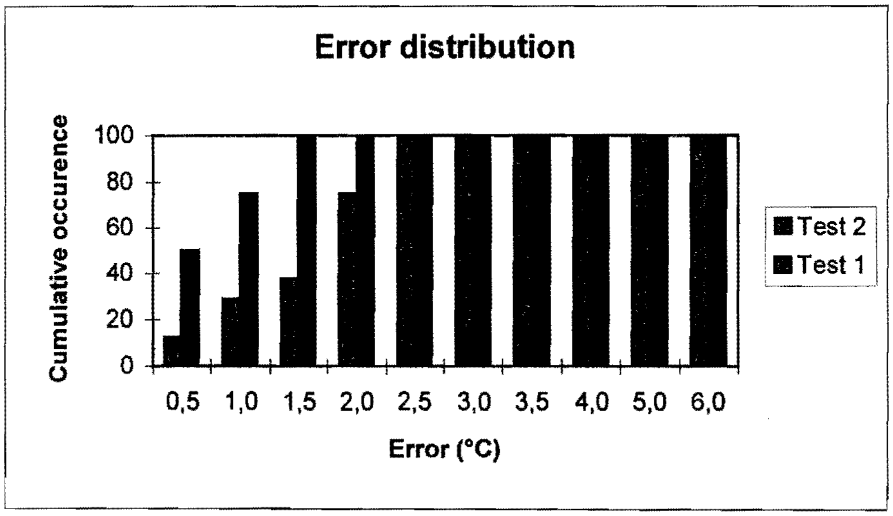




STUDY 23

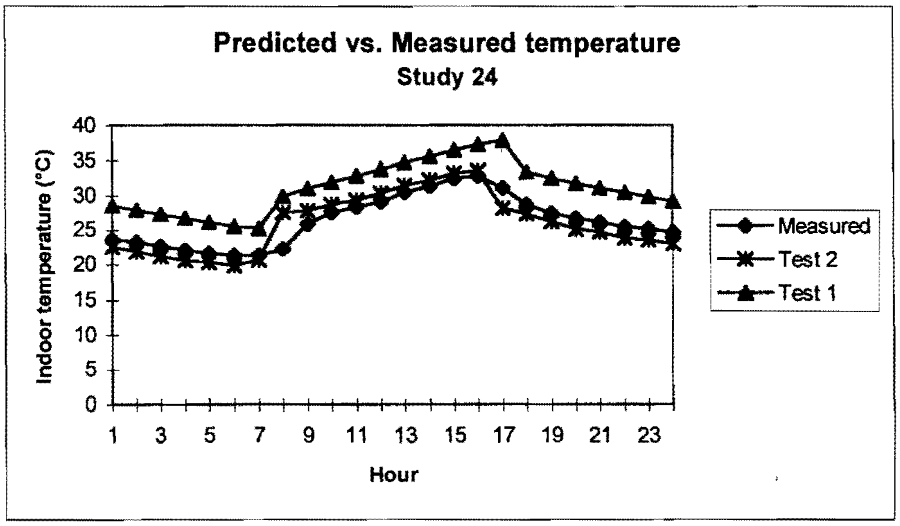
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	17.6	15.7	18.8	13	21.8	21.7	22.5
2	17.3	15.4	18.4	14	22.7	22.3	23.1
3	16.8	14.8	17.9	15	23.3	22.7	23.4
4	16.3	14.3	17.4	16	23.4	22.8	23.6
5	15.7	13.7	16.8	17	23.3	22.5	23.3
6	15.4	13.1	16.3	18	22.6	21.3	22.6
7	15.4	13.1	16.0	19	21.9	20.3	22.1
8	16.6	14.7	16.5	20	21.1	19.2	21.5
9	17.9	16.2	17.6	21	20.6	18.2	21.0
10	19.0	17.8	18.9	22	19.9	17.6	20.4
11	19.9	19.2	20.3	23	18.8	16.9	19.9
12	20.9	20.6	21.5	24	18.5	16.5	19.4

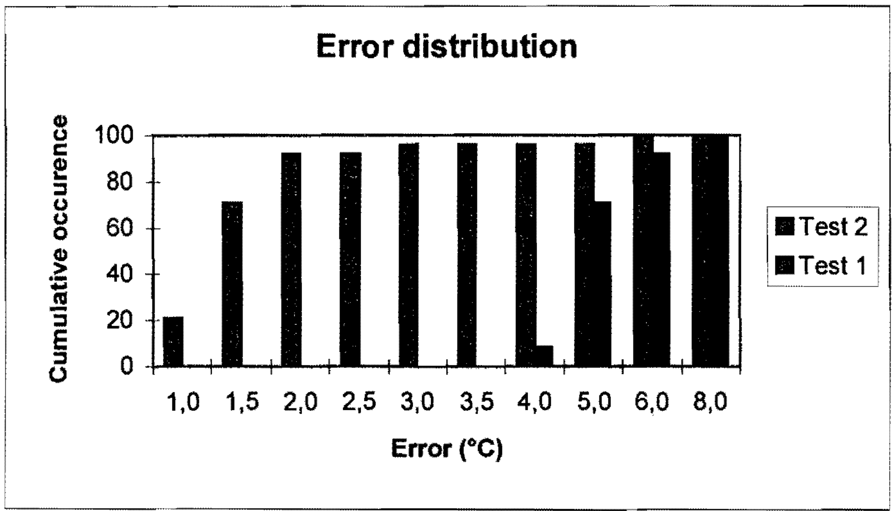




STUDY 24

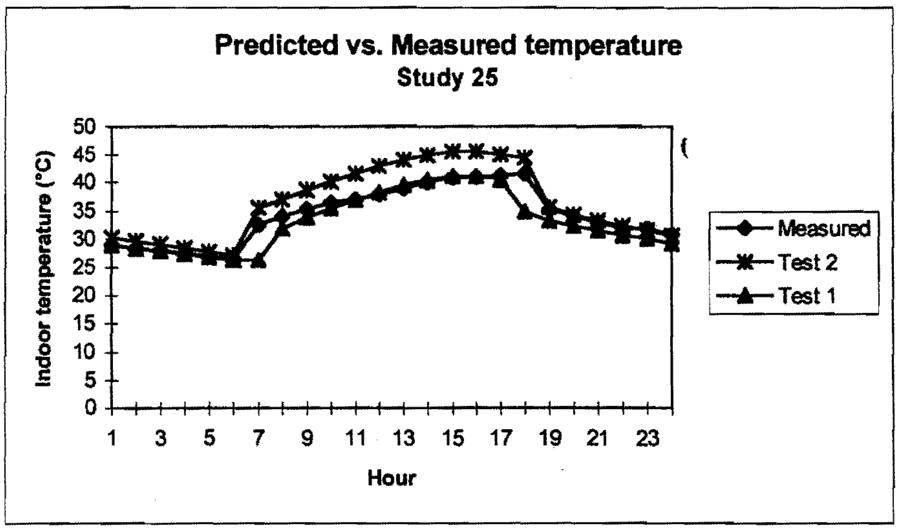
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.6	22.5	28.5	13	30.5	31.4	34.7
2	23.2	21.8	27.9	14	31.4	32.2	35.5
3	22.6	21.1	27.2	15	32.5	33.2	36.4
4	22.0	20.6	26.6	16	32.9	33.6	37.2
5	21.6	20.2	26.1	17	31.1	28.2	37.9
6	21.3	19.8	25.5	18	28.7	27.3	33.4
7	21.3	20.7	25.2	19	27.4	26.1	32.5
8	22.2	27.5	30.0	20	26.7	25.1	31.8
9	25.8	27.8	31.0	21	26.1	24.7	31.2
10	27.5	28.8	32.0	22	25.4	23.8	30.5
11	28.3	29.4	32.9	23	25.1	23.5	29.8
12	29.1	30.4	33.8	24	24.6	22.9	29.2

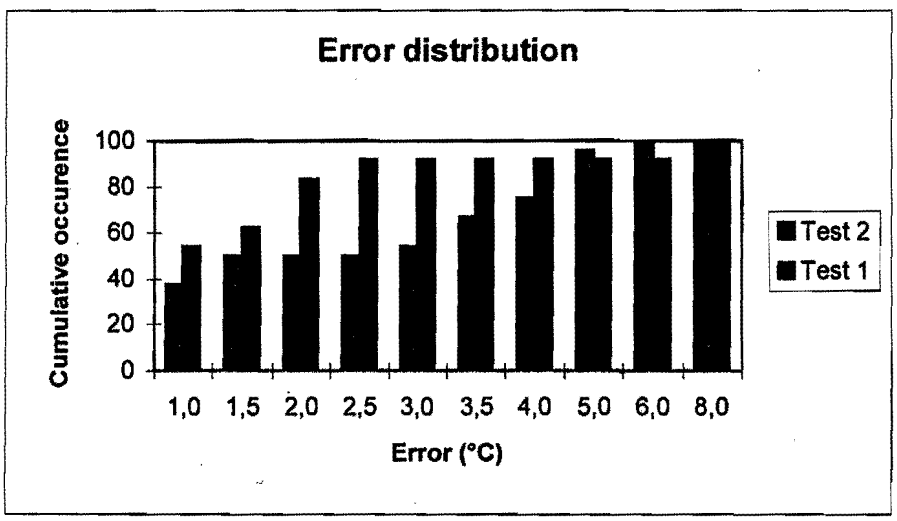




STUDY 25

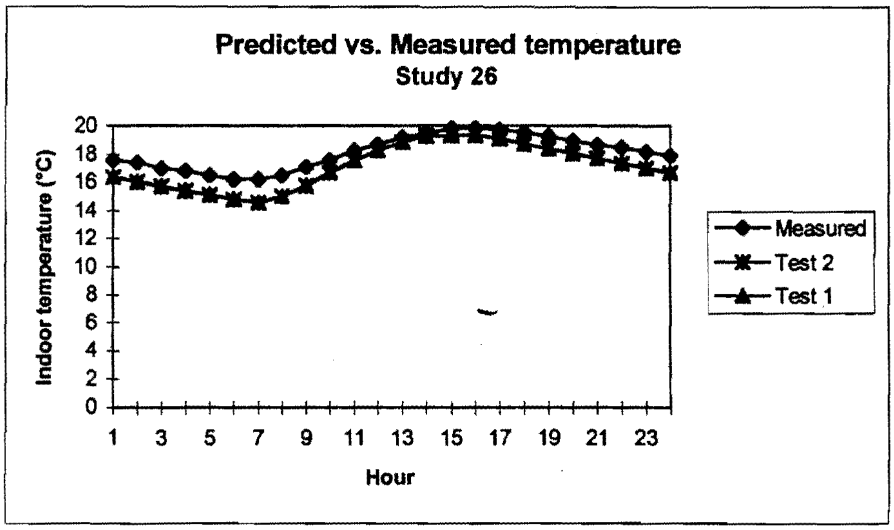
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	29.0	30.2	28.9	13	39.0	44.1	39.5
2	28.3	29.6	28.4	14	40.0	44.9	40.4
3	28.0	29.0	27.9	15	40.8	45.6	41.1
4	27.5	28.4	27.4	16	41.0	45.6	41.1
5	27.0	27.8	26.8	17	41.2	45.1	40.6
6	26.5	27.2	26.2	18	41.5	44.5	34.9
7	32.5	35.6	26.3	19	35.3	35.6	33.2
8	34.0	37.1	31.8	20	34.0	34.2	32.3
9	35.3	38.6	33.7	21	33.0	33.2	31.5
10	36.5	40.1	35.4	22	32.0	32.3	30.7
11	37.0	41.6	36.9	23	31.8	31.5	30.1
12	38.0	43.0	38.3	24	30.8	30.6	29.2

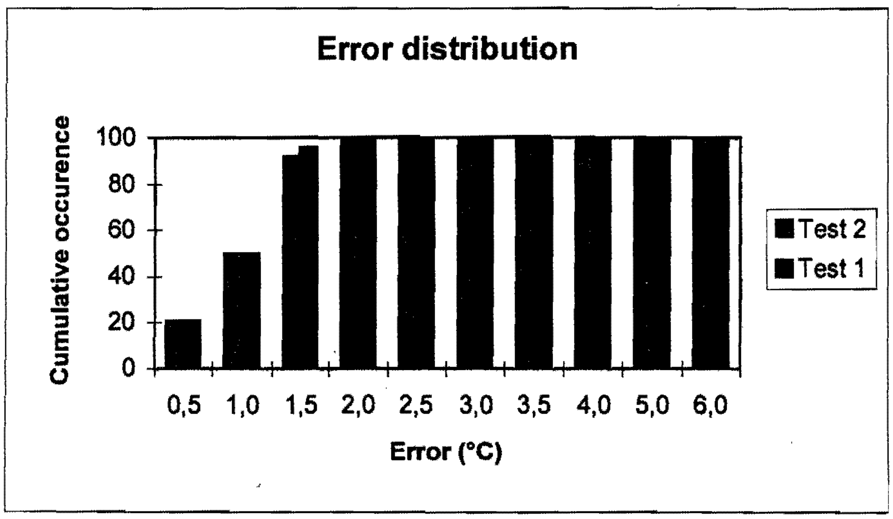




STUDY 26

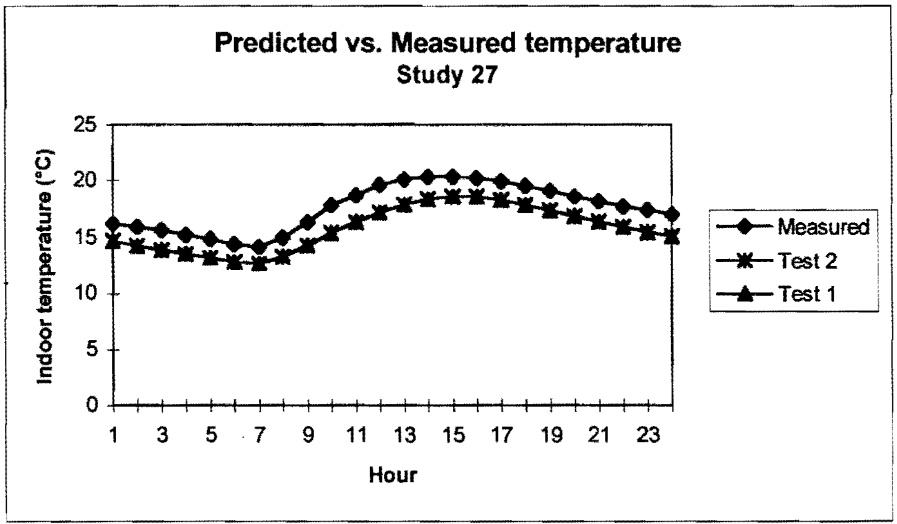
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	17.6	16.3	16.4	13	19.2	18.9	18.9
2	17.4	16.0	16.1	14	19.5	19.3	19.3
3	17.0	15.7	15.7	15	19.8	19.4	19.4
4	16.8	15.4	15.4	16	19.8	19.4	19.4
5	16.5	15.1	15.1	17	19.7	19.1	19.2
6	16.2	14.8	14.8	18	19.6	18.7	18.8
7	16.2	14.5	14.6	19	19.3	18.4	18.4
8	16.5	15.0	15.0	20	19.0	18.1	18.1
9	17.1	15.8	15.8	21	18.7	17.7	17.8
10	17.6	16.7	16.7	22	18.5	17.4	17.4
11	18.3	17.5	17.6	23	18.2	17.0	17.1
12	18.7	18.3	18.3	24	17.9	16.7	16.7

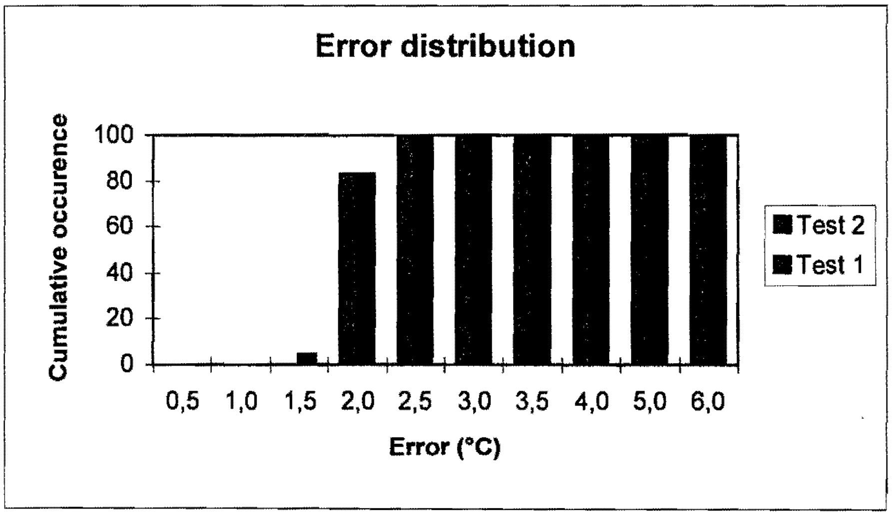




STUDY 27

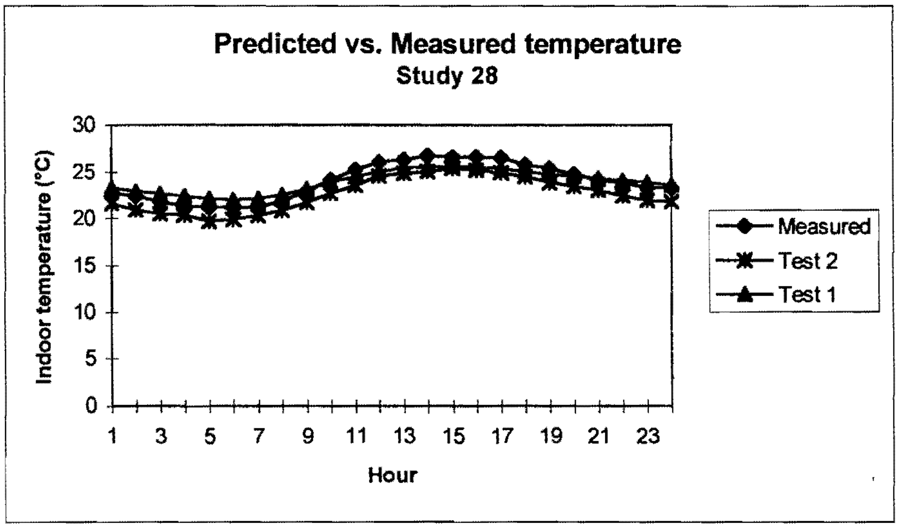
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	16.2	14.7	14.7	13	20.1	17.9	17.9
2	15.9	14.3	14.3	14	20.3	18.3	18.3
3	15.6	13.9	13.9	15	20.3	18.6	18.6
4	15.2	13.5	13.6	16	20.2	18.6	18.6
5	14.9	13.2	13.2	17	19.9	18.3	18.3
6	14.4	12.8	12.9	18	19.5	17.8	17.9
7	14.2	12.7	12.7	19	19.1	17.4	17.4
8	15.0	13.3	13.4	20	18.6	16.8	16.9
9	16.3	14.3	14.3	21	18.2	16.4	16.4
10	17.8	15.4	15.4	22	17.7	15.9	15.9
11	18.7	16.3	16.4	23	17.4	15.5	15.5
12	19.6	17.2	17.2	24	17.0	15.1	15.1

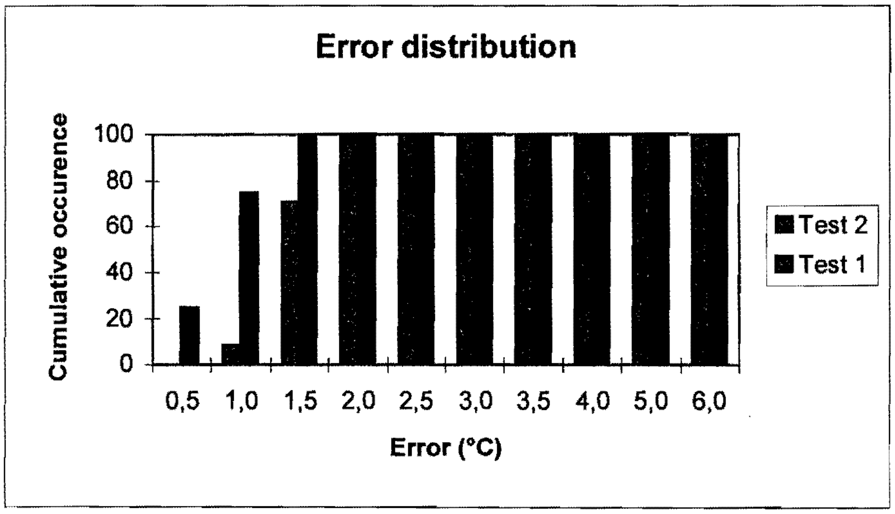




STUDY 28

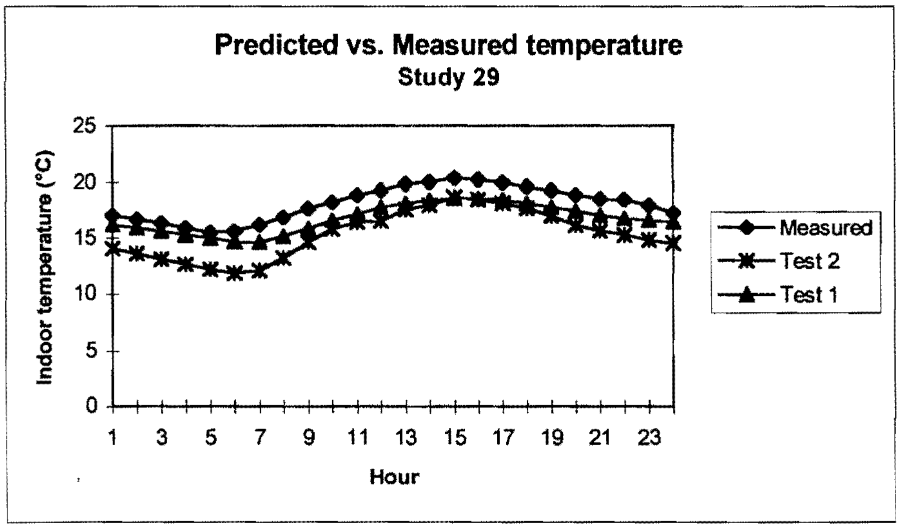
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.8	21.6	23.3	13	26.4	24.9	25.5
2	22.4	20.9	23.0	14	26.8	25.1	25.6
3	21.8	20.5	22.7	15	26.7	25.4	25.7
4	21.3	20.3	22.5	16	26.7	25.2	25.5
5	21.2	19.6	22.2	17	26.6	24.9	25.4
6	21.2	19.8	22.0	18	25.8	24.5	25.1
7	21.2	20.3	22.2	19	25.4	23.9	24.8
8	21.9	20.8	22.6	20	24.8	23.4	24.5
9	23.0	21.7	23.2	21	24.2	23.1	24.3
10	24.2	22.7	23.9	22	23.8	22.4	24.1
11	25.3	23.6	24.5	23	23.3	22.0	23.9
12	26.1	24.6	25.1	24	23.3	21.8	23.6

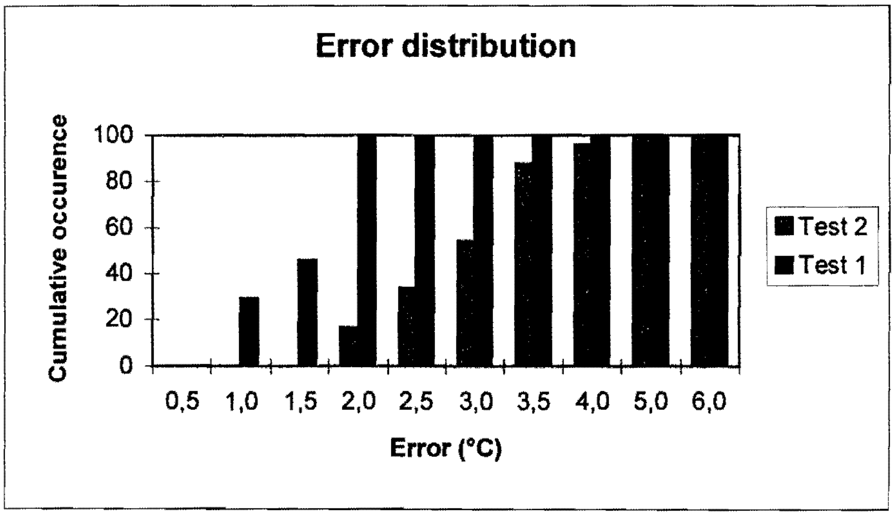




STUDY 29

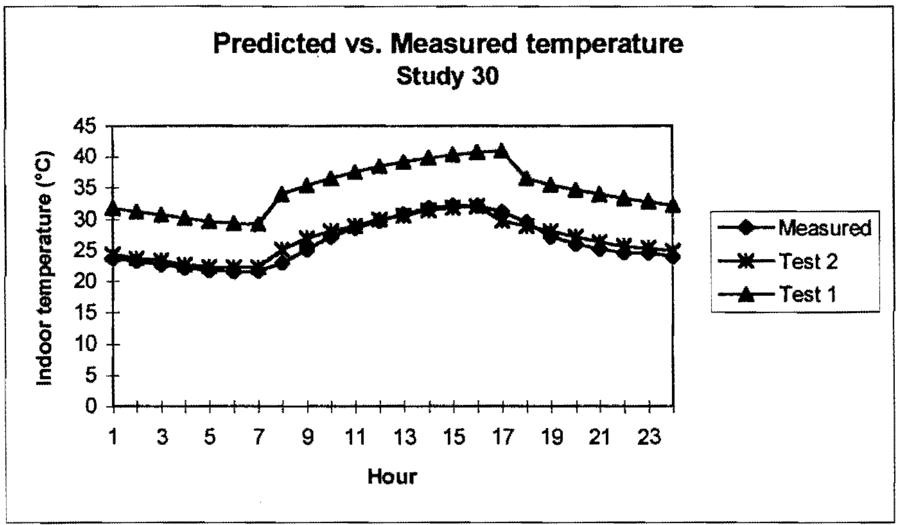
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	17.1	14.1	16.2	13	19.9	17.6	18.2
2	16.7	13.6	15.9	14	20.1	18.0	18.5
3	16.4	13.1	15.6	15	20.4	18.8	18.7
4	15.9	12.6	15.3	16	20.3	18.5	18.6
5	15.5	12.2	15.0	17	20.0	18.2	18.5
6	15.6	11.8	14.7	18	19.7	17.7	18.2
7	16.2	12.0	14.7	19	19.3	17.0	17.8
8	16.9	13.2	15.2	20	18.9	16.1	17.5
9	17.7	14.6	15.9	21	18.6	15.6	17.1
10	18.3	15.8	16.6	22	18.5	15.3	16.8
11	18.9	16.4	17.2	23	18.0	14.8	16.6
12	19.3	16.5	17.8	24	17.3	14.5	16.4

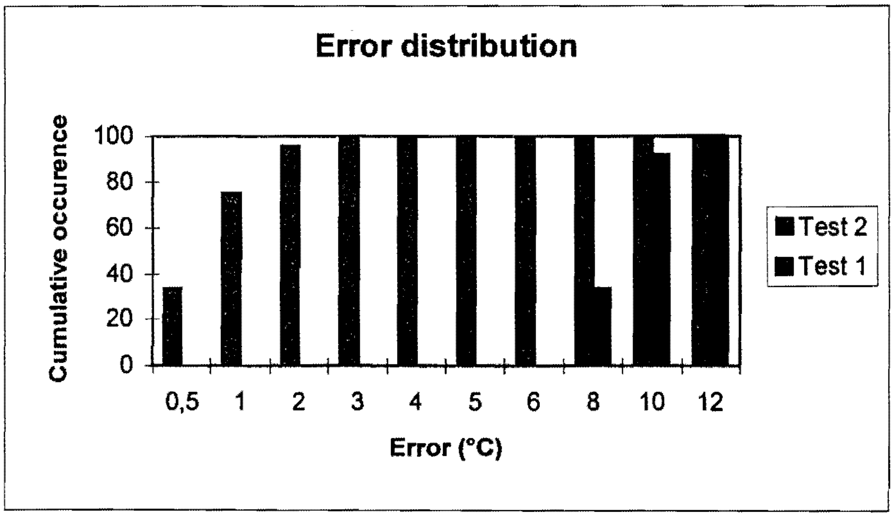




STUDY 30

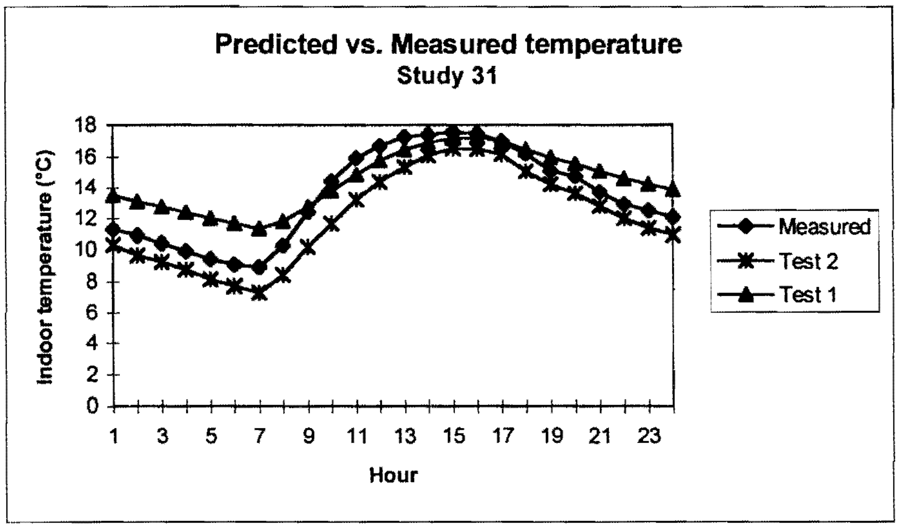
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.8	24.5	31.8	13	30.8	30.7	39.2
2	23.3	23.7	31.3	14	31.8	31.4	39.8
3	22.7	23.4	30.7	15	32.2	31.9	40.3
4	22.2	22.7	30.2	16	32.2	32.0	40.7
5	21.8	22.4	29.7	17	31.2	29.8	40.9
6	21.6	22.3	29.4	18	29.6	28.9	36.5
7	21.7	22.3	29.3	19	27.3	28.2	35.4
8	23.0	25.2	34.0	20	26.1	27.2	34.6
9	25.2	26.9	35.3	21	25.3	26.4	34.0
10	27.3	28.1	36.4	22	24.7	25.8	33.4
11	28.6	29.0	37.5	23	24.7	25.4	32.9
12	29.8	30.0	38.4	24	24.1	25.0	32.3

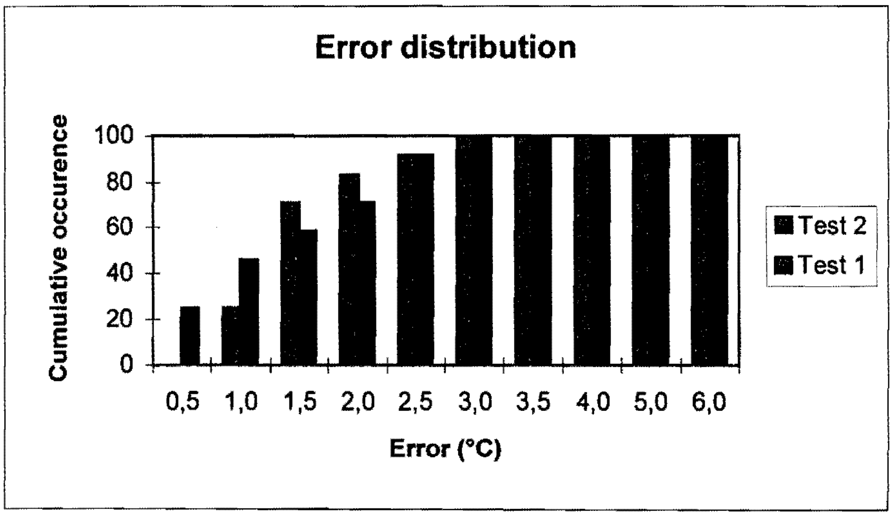




STUDY 31

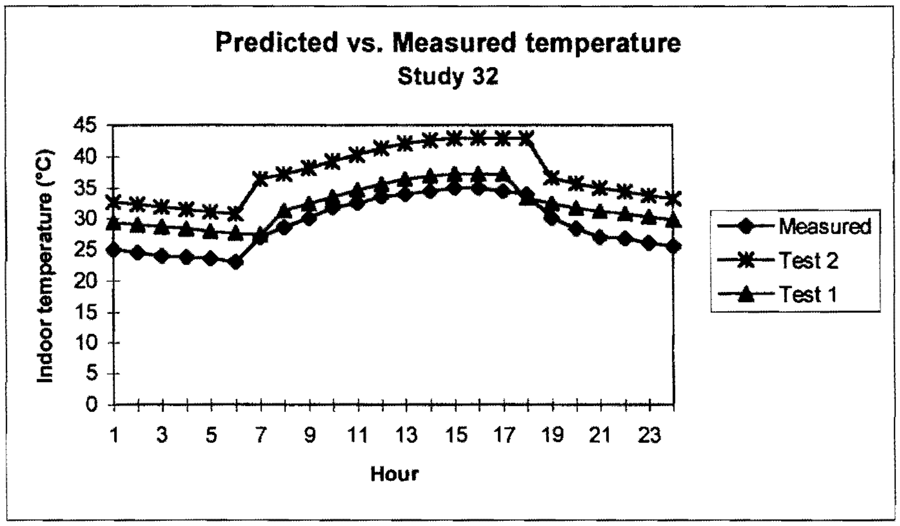
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	11.3	10.3	13.5	13	17.3	15.4	16.5
2	10.9	9.7	13.1	14	17.4	16.1	16.9
3	10.4	9.3	12.7	15	17.6	16.6	17.2
4	9.9	8.7	12.4	16	17.5	16.5	17.2
5	9.4	8.1	12.0	17	17.0	16.2	17.1
6	9.1	7.7	11.7	18	16.2	15.1	16.4
7	8.9	7.3	11.4	19	15.1	14.2	16.0
8	10.3	8.4	11.8	20	14.7	13.6	15.6
9	12.4	10.2	12.8	21	13.7	12.8	15.1
10	14.4	11.7	13.8	22	12.9	12.0	14.6
11	15.9	13.2	14.9	23	12.5	11.4	14.2
12	16.7	14.4	15.8	24	12.1	11.0	13.9

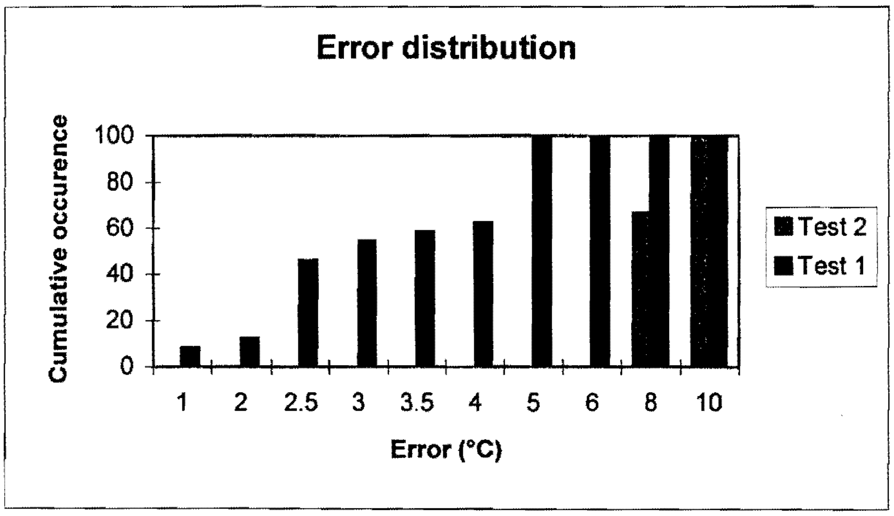




STUDY 32

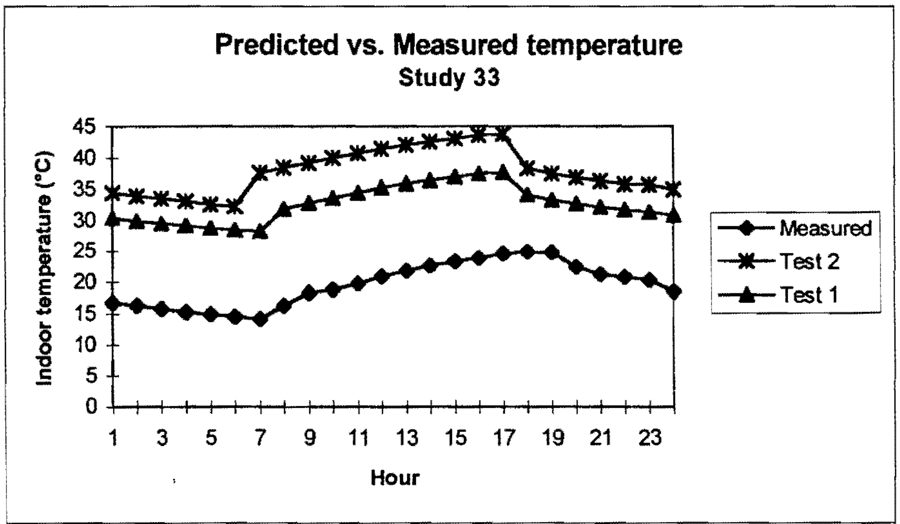
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.0	32.7	29.3	13	34.0	42.1	36.4
2	24.5	32.3	28.9	14	34.5	42.6	37.0
3	24.0	31.9	28.6	15	35.0	42.9	37.3
4	23.8	31.5	28.3	16	35.0	43.0	37.3
5	23.5	31.1	28.0	17	34.5	43.0	37.3
6	23.0	30.7	27.7	18	34.0	42.9	33.4
7	27.0	36.4	27.4	19	30.0	36.7	32.4
8	28.5	37.3	31.2	20	28.3	35.7	31.7
9	30.0	38.2	32.4	21	27.0	35.1	31.2
10	31.8	39.3	33.5	22	26.8	34.4	30.7
11	32.5	40.4	34.7	23	26.0	33.8	30.2
12	33.5	41.3	35.7	24	25.5	33.2	29.7

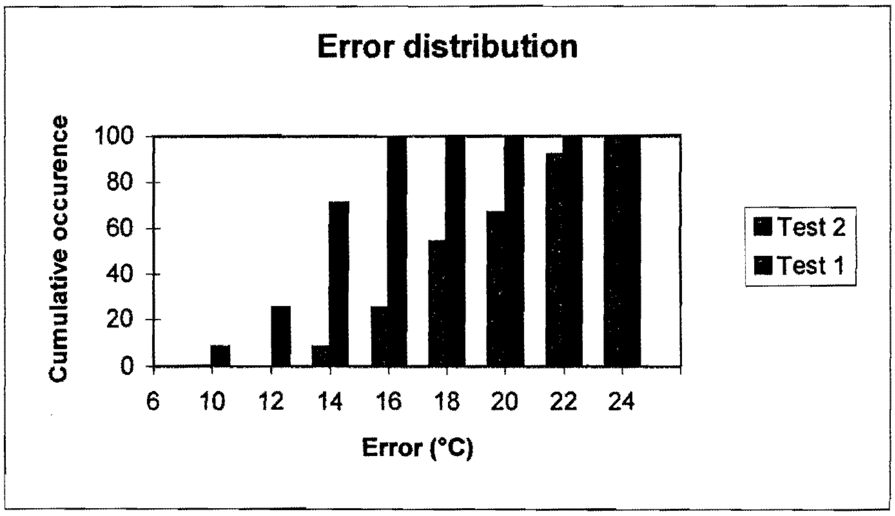




STUDY 33

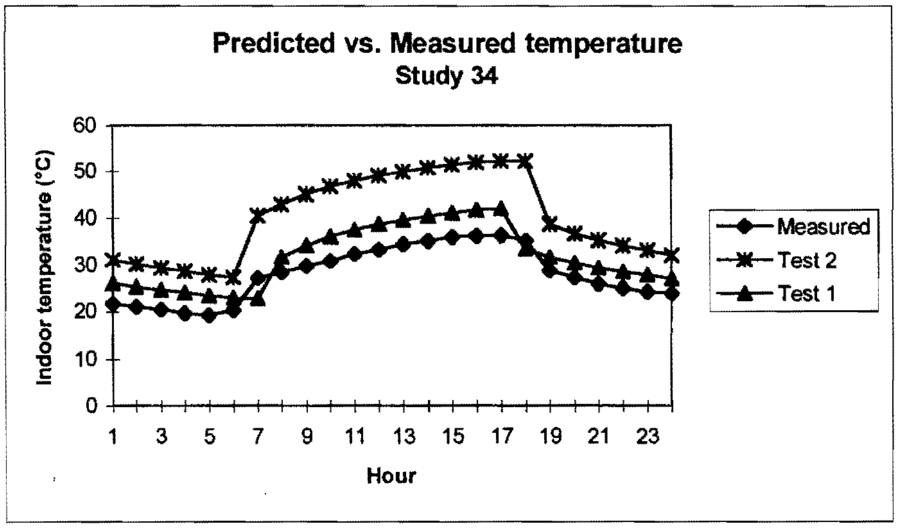
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	16.7	34.5	30.4	13	21.8	42.1	35.9
2	16.2	34.0	29.9	14	22.6	42.6	36.5
3	15.7	33.5	29.5	15	23.3	43.1	37.0
4	15.2	33.1	29.1	16	23.9	43.6	37.5
5	14.9	32.6	28.7	17	24.6	43.8	37.7
6	14.5	32.3	28.4	18	24.9	38.4	34.2
7	14.2	37.6	28.3	19	24.8	37.5	33.4
8	16.3	38.4	31.8	20	22.4	36.9	32.7
9	18.2	39.2	32.8	21	21.1	36.4	32.2
10	18.8	40.0	33.7	22	20.7	35.9	31.8
11	19.7	40.7	34.5	23	20.2	35.8	31.3
12	20.8	41.5	35.3	24	18.4	35.0	30.9

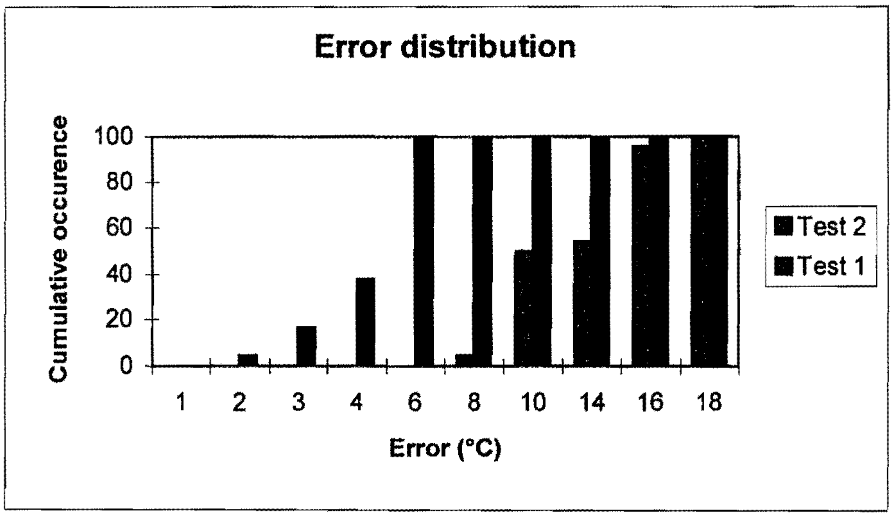




STUDY 34

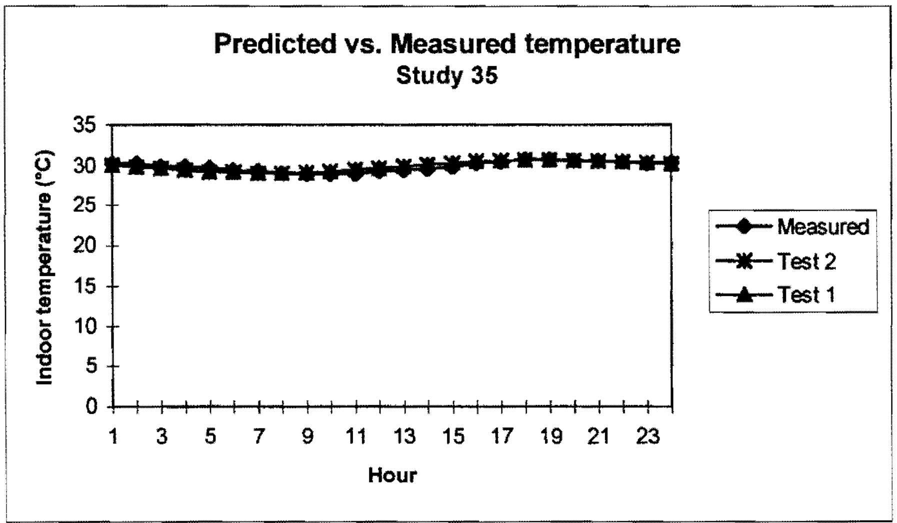
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.7	31.1	26.0	13	34.4	49.9	39.6
2	21.0	30.2	25.3	14	35.1	50.7	40.4
3	20.4	29.3	24.6	15	36.0	51.4	41.2
4	19.6	28.6	24.0	16	36.3	51.9	41.8
5	19.2	27.8	23.4	17	36.4	52.3	42.1
6	20.3	27.2	22.9	18	35.1	52.2	33.5
7	27.1	40.5	22.8	19	28.7	38.7	31.7
8	28.3	42.9	31.7	20	27.2	36.7	30.4
9	29.7	44.9	34.2	21	25.9	35.3	29.3
10	30.9	46.6	36.1	22	25.0	34.1	28.5
11	32.3	47.9	37.6	23	24.2	33.1	27.7
12	33.3	49.0	38.7	24	23.9	32.1	26.9

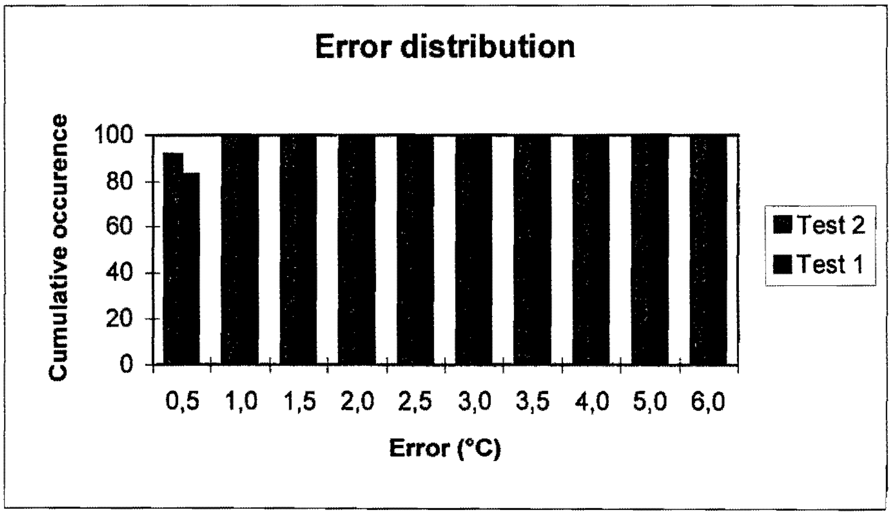




STUDY 35

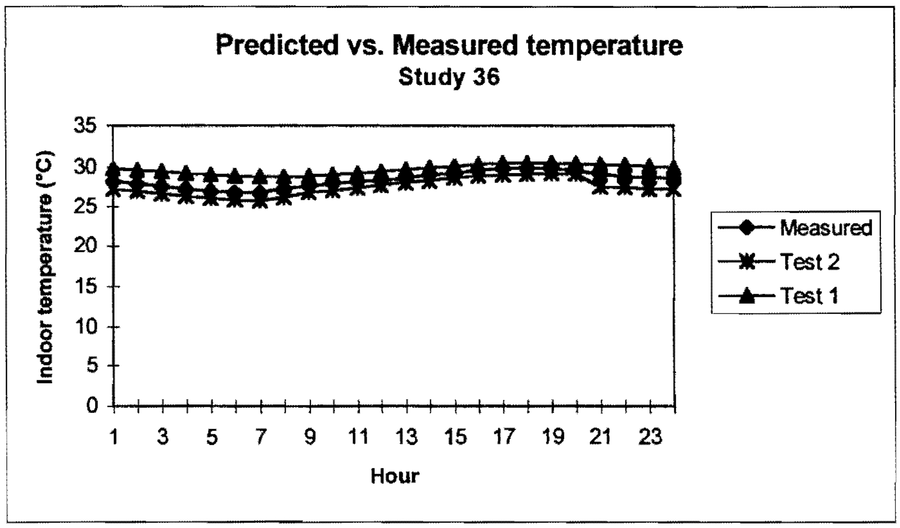
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	30.3	30.0	30.1	13	29.4	29.9	29.9
2	30.3	29.9	29.9	14	29.6	30.1	30.1
3	29.9	29.7	29.7	15	29.8	30.3	30.3
4	29.9	29.4	29.5	16	30.3	30.5	30.5
5	29.7	29.2	29.2	17	30.5	30.7	30.7
6	29.4	29.1	29.2	18	30.8	30.7	30.7
7	29.3	29.0	29.1	19	30.8	30.7	30.7
8	29.0	29.0	29.0	20	30.7	30.7	30.7
9	28.9	29.1	29.1	21	30.6	30.6	30.6
10	28.9	29.3	29.3	22	30.5	30.5	30.5
11	28.9	29.5	29.5	23	30.3	30.4	30.4
12	29.3	29.7	29.7	24	30.5	30.2	30.2

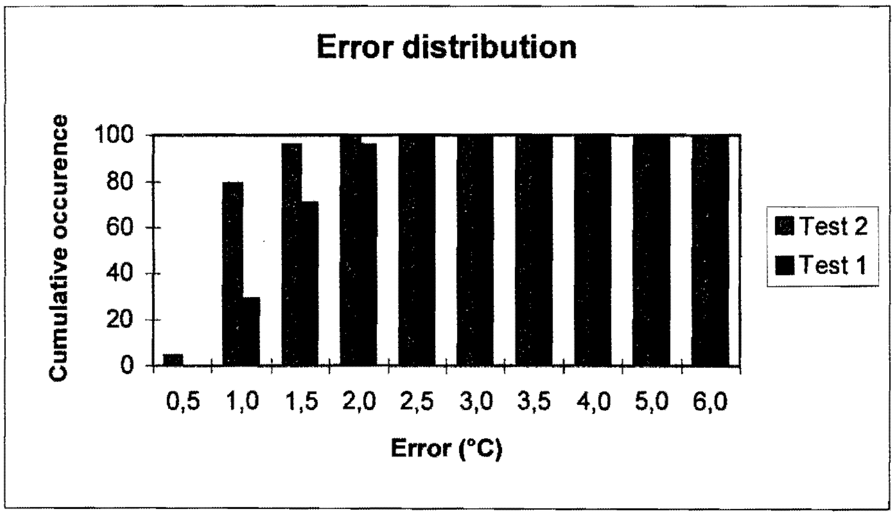




STUDY 36

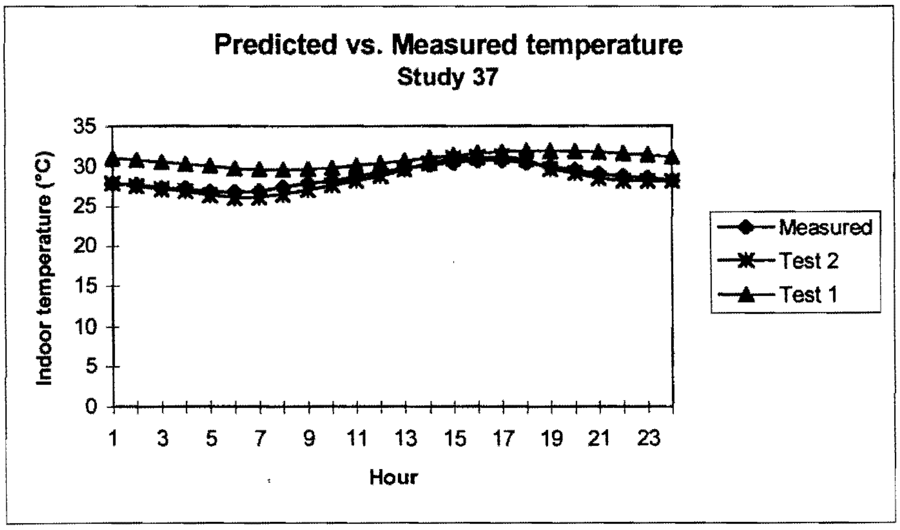
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	28.2	27.3	29.8	13	28.6	28.0	29.7
2	27.9	27.0	29.6	14	29.0	28.3	29.9
3	27.6	26.7	29.4	15	29.2	28.6	30.1
4	27.2	26.4	29.2	16	29.6	28.8	30.3
5	27.0	26.1	29.0	17	29.8	29.0	30.4
6	26.8	25.9	28.9	18	29.8	29.1	30.5
7	26.8	25.8	28.8	19	29.8	29.1	30.5
8	27.3	26.2	28.8	20	29.5	29.1	30.4
9	27.6	26.9	28.9	21	29.1	27.6	30.3
10	27.9	27.1	29.0	22	28.8	27.5	30.2
11	28.1	27.4	29.2	23	28.7	27.3	30.1
12	28.3	27.7	29.4	24	28.5	27.3	29.9

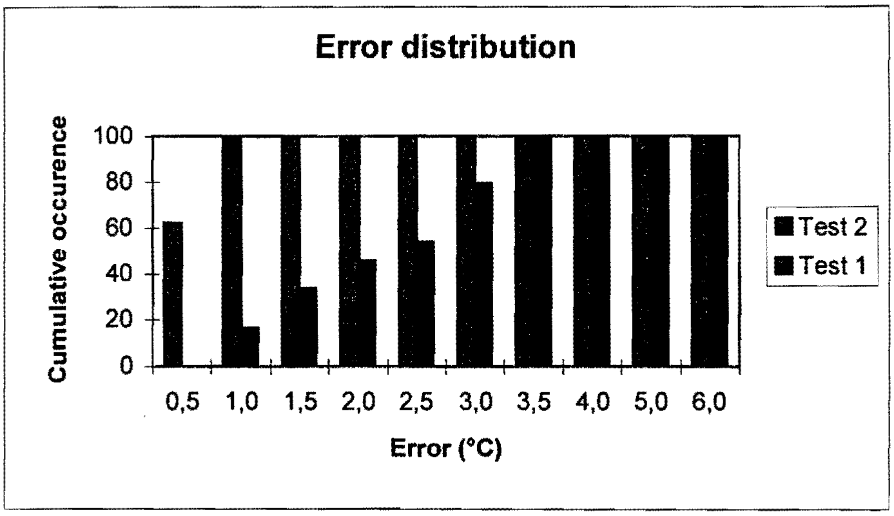




STUDY 37

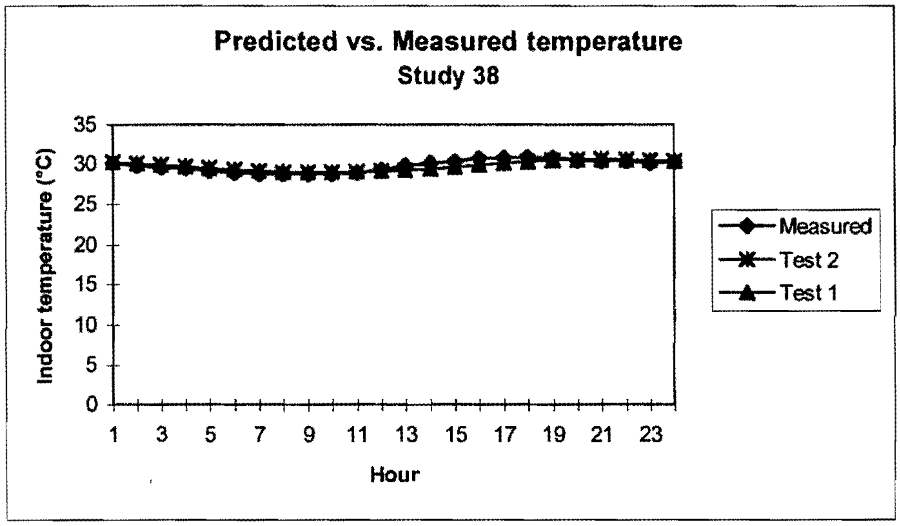
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	27.9	27.9	31.0	13	29.7	29.6	30.7
2	27.7	27.5	30.8	14	30.2	30.4	31.0
3	27.3	27.2	30.5	15	30.5	30.9	31.4
4	27.2	26.9	30.3	16	30.8	31.1	31.6
5	26.8	26.4	30.0	17	30.8	31.2	31.8
6	26.8	26.1	29.8	18	30.5	30.9	31.9
7	26.9	26.2	29.6	19	30.0	29.6	31.9
8	27.4	26.5	29.6	20	29.6	29.1	31.8
9	27.9	27.0	29.7	21	29.1	28.6	31.7
10	28.2	27.6	29.9	22	28.8	28.2	31.6
11	28.7	28.2	30.1	23	28.6	28.2	31.4
12	29.3	28.8	30.4	24	28.3	28.2	31.2

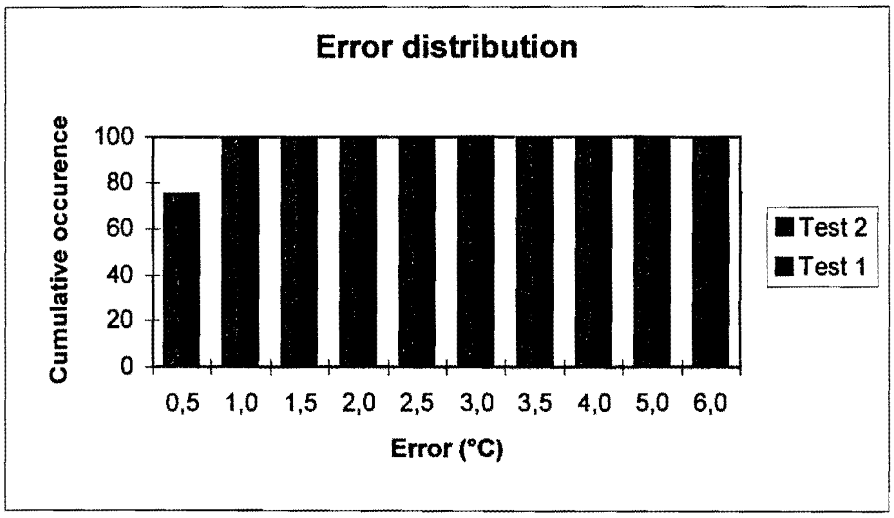




STUDY 38

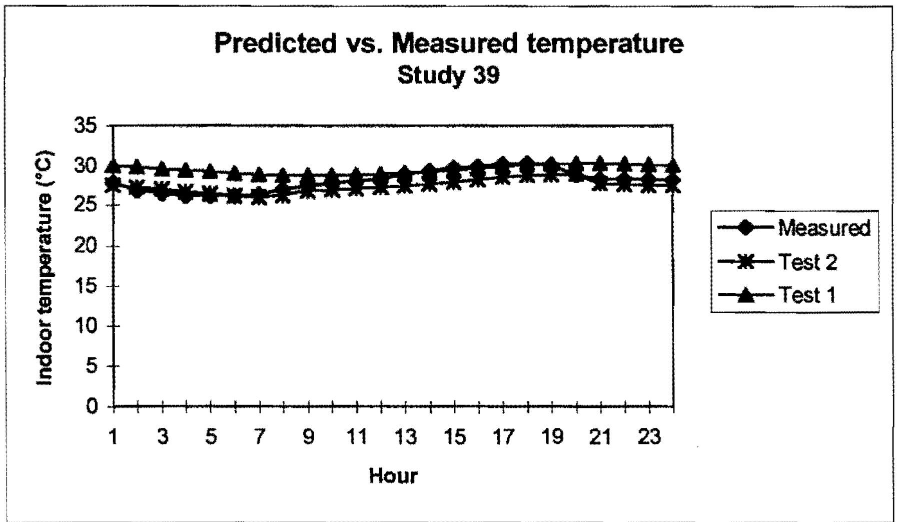
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	30.1	30.2	30.2	13	29.8	29.3	29.3
2	29.8	30.1	30.1	14	30.1	29.4	29.4
3	29.6	29.9	29.9	15	30.3	29.6	29.6
4	29.5	29.7	29.7	16	30.7	29.9	29.9
5	29.2	29.5	29.5	17	30.8	30.1	30.1
6	28.9	29.3	29.3	18	30.9	30.3	30.3
7	28.8	29.2	29.2	19	30.8	30.5	30.5
8	28.8	29.0	29.1	20	30.5	30.5	30.5
9	28.8	29.0	29.0	21	30.4	30.6	30.6
10	28.8	29.0	29.0	22	30.4	30.5	30.5
11	28.9	29.1	29.1	23	30.1	30.5	30.5
12	29.3	29.2	29.2	24	30.3	30.4	30.4

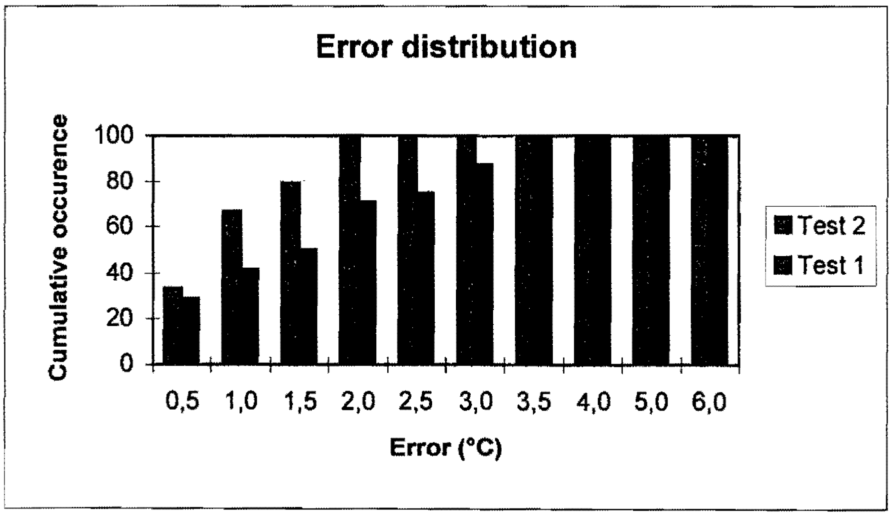




STUDY 39

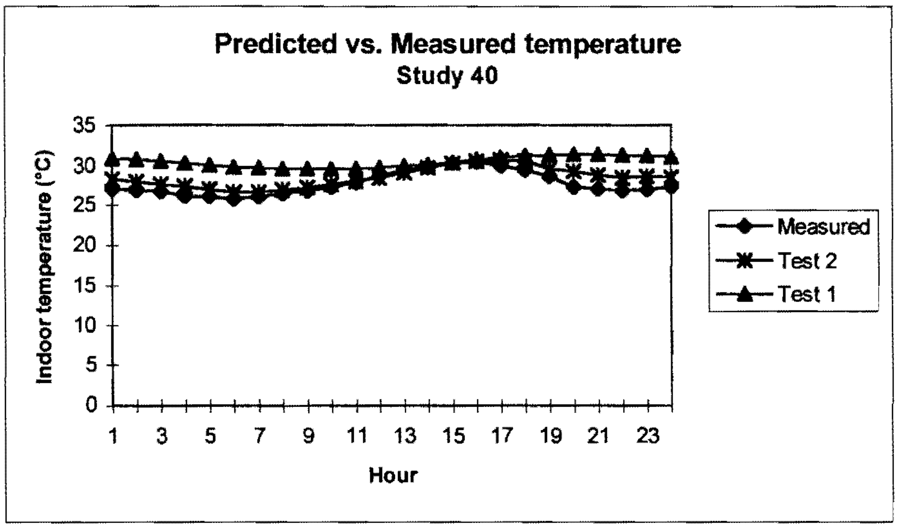
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	27.8	27.5	29.9	13	28.9	27.4	29.1
2	26.8	27.3	29.8	14	29.3	27.6	29.2
3	26.5	27.0	29.6	15	29.7	27.9	29.4
4	26.2	26.7	29.4	16	29.9	28.2	29.7
5	26.2	26.4	29.2	17	30.2	28.5	29.9
6	26.2	26.1	29.0	18	30.3	28.7	30.1
7	26.3	26.0	28.9	19	30.1	28.9	30.2
8	27.0	26.3	28.8	20	28.8	29.0	30.3
9	27.4	26.8	28.8	21	28.3	27.7	30.3
10	27.8	26.9	28.8	22	28.3	27.6	30.3
11	28.0	27.0	28.8	23	28.3	27.5	30.2
12	28.3	27.2	28.9	24	28.2	27.5	30.1

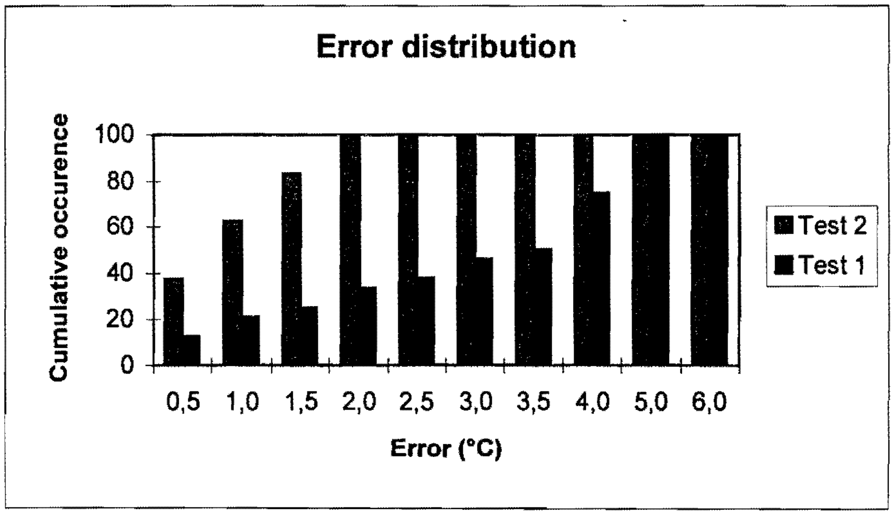




STUDY 40

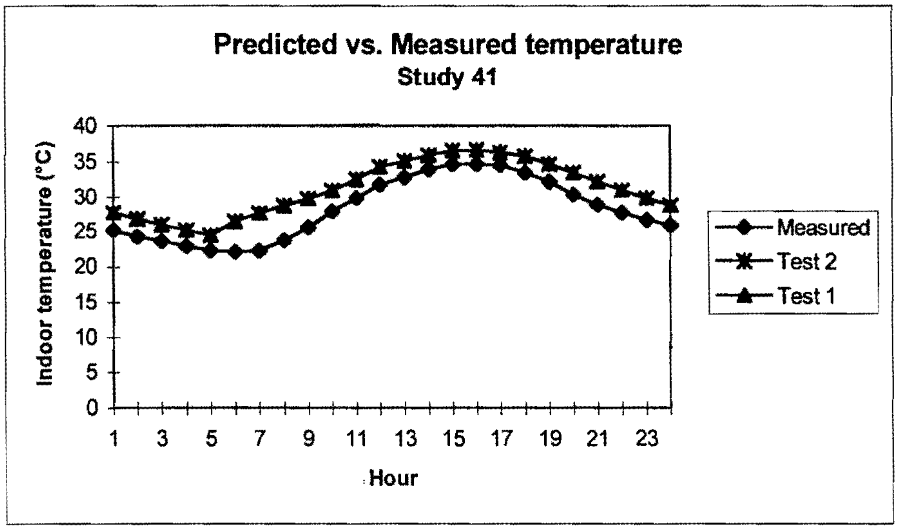
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	27.1	28.2	31.0	13	29.4	29.1	29.9
2	26.9	28.0	30.8	14	29.8	29.7	30.1
3	26.7	27.6	30.6	15	30.3	30.3	30.4
4	26.2	27.4	30.3	16	30.5	30.6	30.8
5	26.1	26.9	30.1	17	30.0	30.7	31.0
6	25.8	26.6	29.9	18	29.4	30.6	31.3
7	26.1	26.7	29.7	19	28.6	29.6	31.4
8	26.4	26.9	29.6	20	27.3	29.2	31.4
9	26.8	27.3	29.6	21	27.1	28.7	31.4
10	27.3	27.6	29.6	22	26.8	28.4	31.4
11	27.9	28.0	29.7	23	27.0	28.6	31.3
12	28.7	28.4	29.8	24	27.3	28.5	31.1

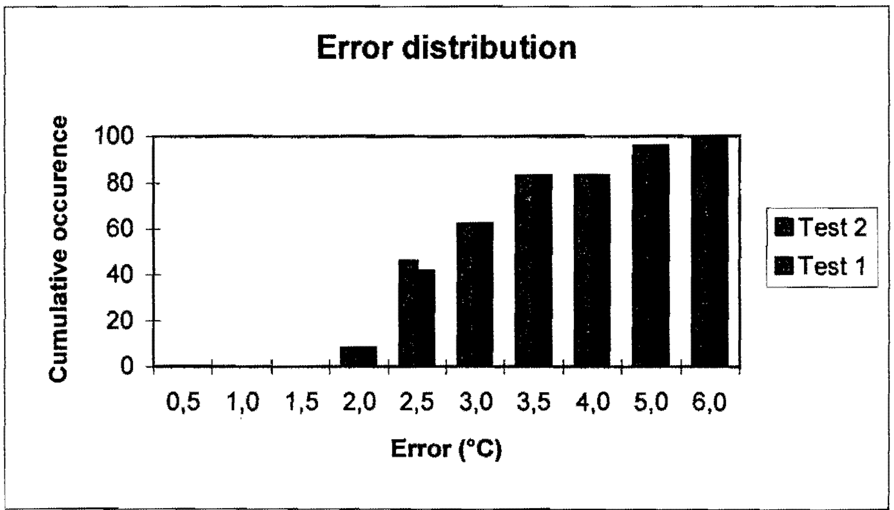




STUDY 41

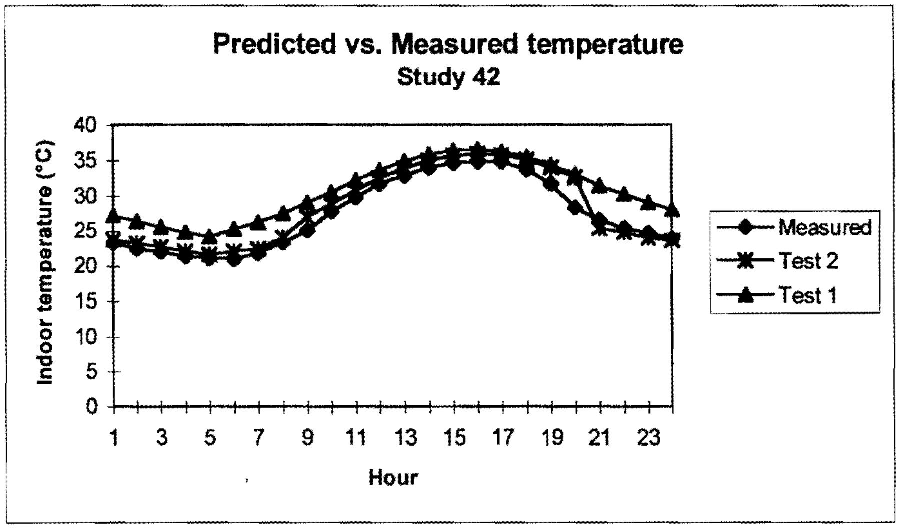
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.2	27.7	27.7	13	32.8	35.1	35.1
2	24.3	26.8	26.8	14	33.9	35.9	36.0
3	23.6	26.0	26.0	15	34.6	36.6	36.6
4	22.9	25.2	25.2	16	34.6	36.7	36.7
5	22.2	24.4	24.4	17	34.5	36.3	36.4
6	22.0	26.4	26.4	18	33.4	35.8	35.8
7	22.2	27.6	27.6	19	32.1	34.6	34.7
8	23.7	28.7	28.7	20	30.3	33.4	33.4
9	25.6	29.7	29.7	21	28.8	32.1	32.2
10	27.9	31.0	31.0	22	27.6	30.9	31.0
11	29.8	32.5	32.5	23	26.6	29.8	29.8
12	31.8	34.3	34.3	24	25.8	28.7	28.7

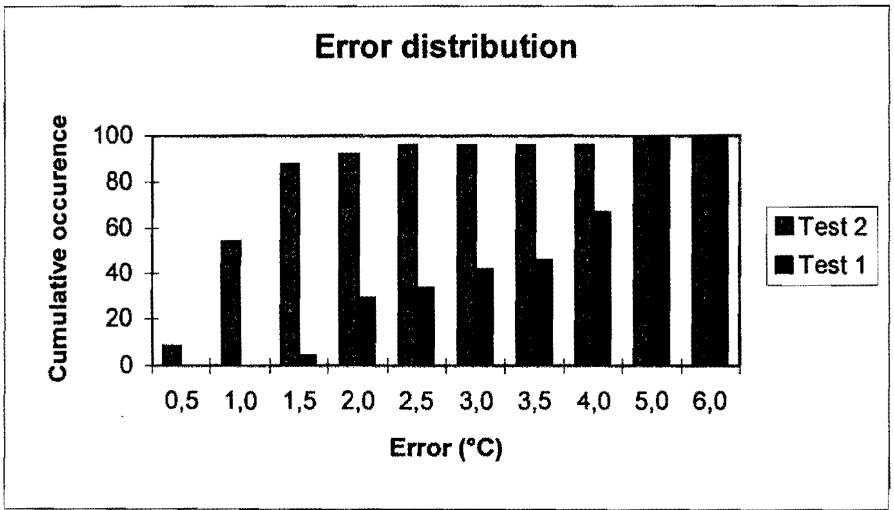




STUDY 42

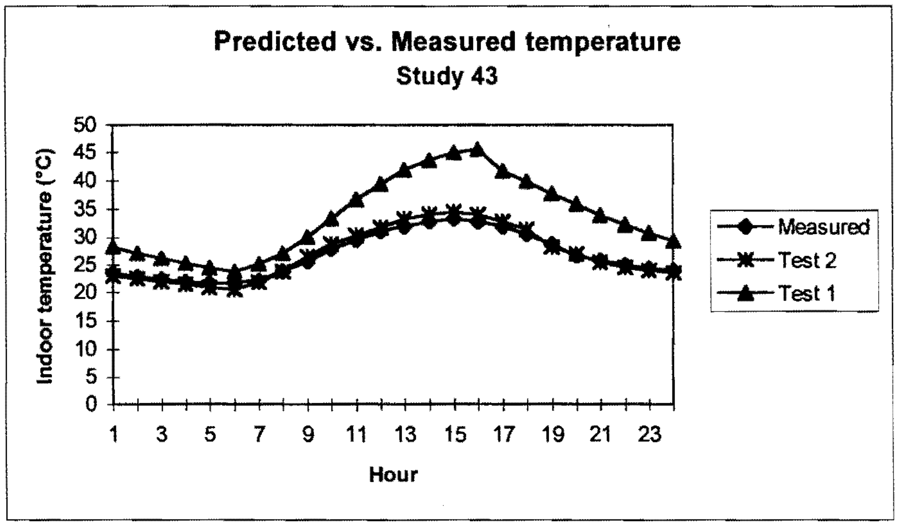
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.3	23.7	27.2	13	32.9	33.9	34.9
2	22.4	23.2	26.4	14	34.0	35.0	35.8
3	21.9	22.7	25.6	15	34.6	35.7	36.4
4	21.3	22.1	24.9	16	34.8	36.0	36.6
5	21.1	21.6	24.2	17	34.8	35.7	36.2
6	20.9	22.1	25.3	18	33.7	35.1	35.5
7	21.8	22.4	26.2	19	31.8	34.0	34.4
8	23.3	24.0	27.5	20	28.3	32.6	33.0
9	25.1	27.0	29.0	21	26.6	25.4	31.5
10	27.8	28.9	30.5	22	25.4	24.9	30.3
11	29.8	30.8	32.2	23	24.7	24.0	29.1
12	31.8	32.5	33.7	24	23.9	23.6	28.0

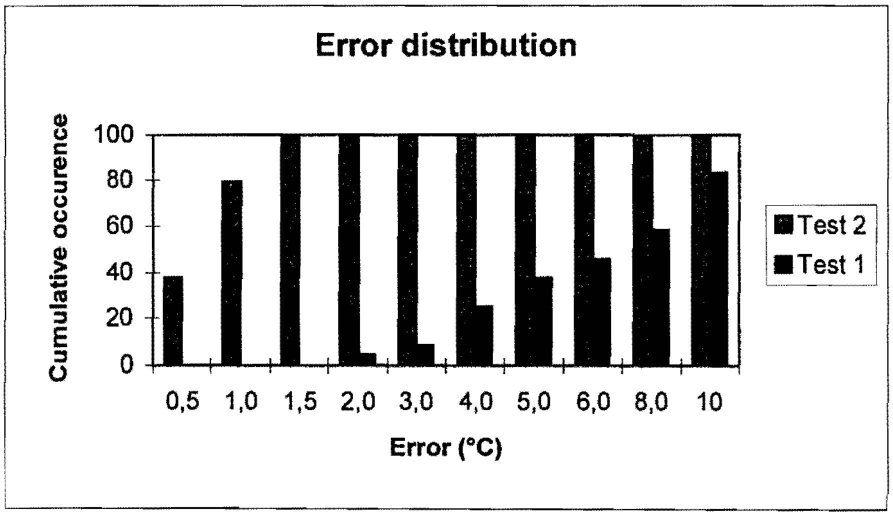




STUDY 43

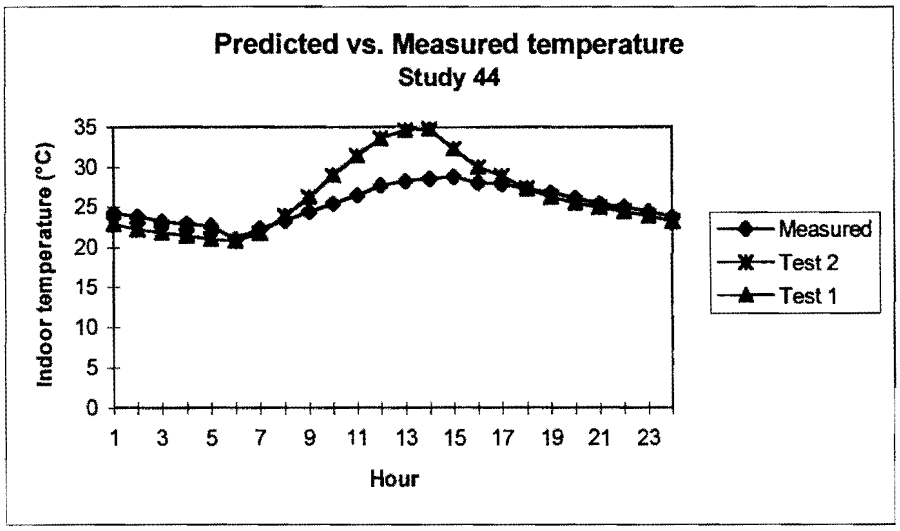
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.5	22.9	28.2	13	31.9	33.2	42.0
2	22.8	22.4	27.1	14	32.8	34.0	43.7
3	22.3	21.9	26.2	15	33.3	34.5	45.1
4	21.9	21.5	25.3	16	32.7	34.0	45.6
5	21.6	20.9	24.4	17	31.9	32.7	41.8
6	21.8	20.5	23.7	18	30.6	31.3	39.9
7	22.1	21.8	25.1	19	28.8	28.2	37.8
8	23.8	23.8	27.1	20	26.6	26.9	35.8
9	25.6	26.5	30.1	21	25.8	25.4	34.0
10	27.9	28.8	33.4	22	25.0	24.6	32.3
11	29.5	30.3	36.7	23	24.3	24.0	30.8
12	31.1	31.7	39.5	24	24.0	23.5	29.4

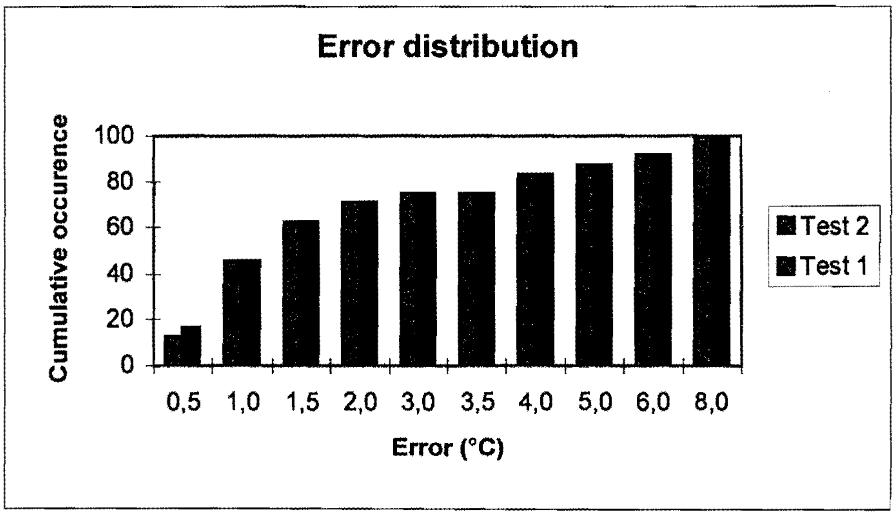




STUDY 44

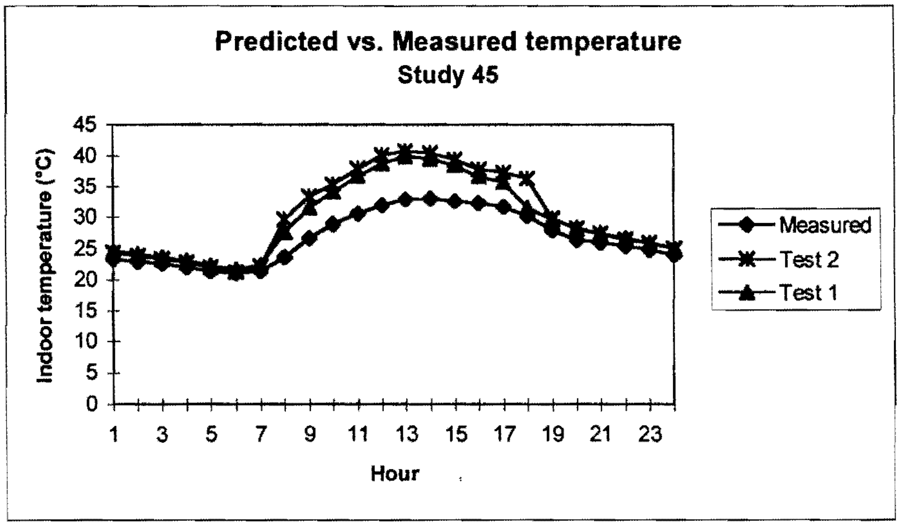
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	24.2	22.9	22.9	13	28.2	34.6	34.6
2	23.8	22.3	22.3	14	28.5	34.8	34.8
3	23.2	21.9	21.9	15	28.8	32.3	32.4
4	22.9	21.4	21.5	16	28.0	30.0	30.0
5	22.7	21.1	21.1	17	27.9	28.8	28.8
6	21.1	20.8	20.8	18	27.3	27.3	27.3
7	22.4	21.8	21.8	19	26.8	26.3	26.3
8	23.3	23.9	23.9	20	26.2	25.5	25.5
9	24.4	26.2	26.2	21	25.4	25.0	25.0
10	25.4	29.0	29.0	22	25.0	24.5	24.5
11	26.5	31.4	31.4	23	24.5	23.9	23.9
12	27.7	33.6	33.6	24	23.8	23.3	23.3

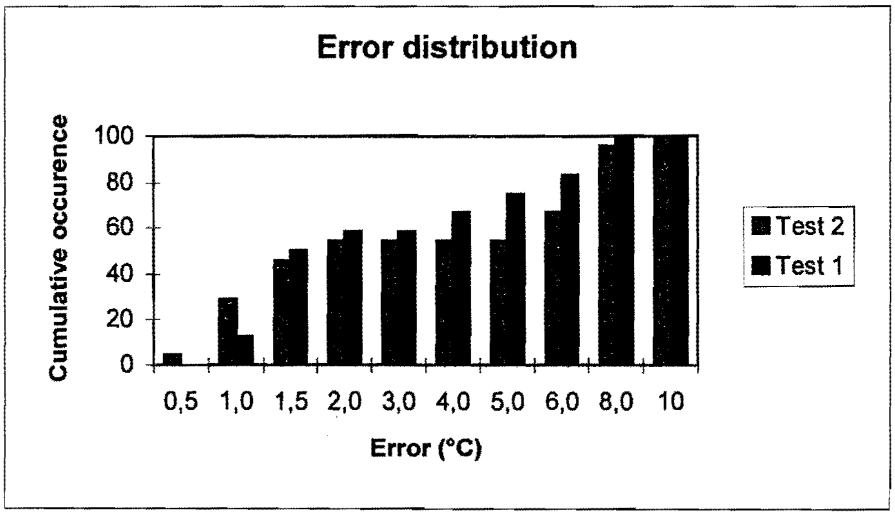




STUDY 45

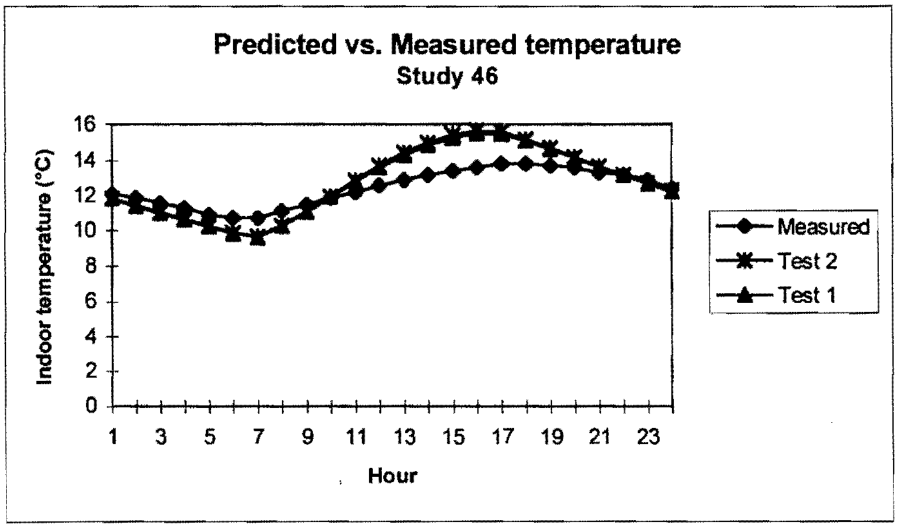
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.3	24.4	24.7	13	32.8	40.7	39.9
2	22.9	23.9	24.2	14	32.9	40.4	39.5
3	22.6	23.3	23.6	15	32.5	39.4	38.4
4	22.0	22.8	23.1	16	32.2	37.8	36.6
5	21.4	22.0	22.3	17	31.6	37.2	35.6
6	21.0	21.3	21.7	18	30.1	36.3	31.4
7	21.4	22.1	22.4	19	27.9	29.7	29.5
8	23.6	29.6	27.6	20	26.4	28.2	28.2
9	26.7	33.3	31.5	21	25.9	27.3	27.4
10	28.9	35.4	34.0	22	25.4	26.5	26.7
11	30.5	37.9	36.6	23	24.8	25.9	26.0
12	31.9	40.1	38.8	24	24.0	25.0	25.1

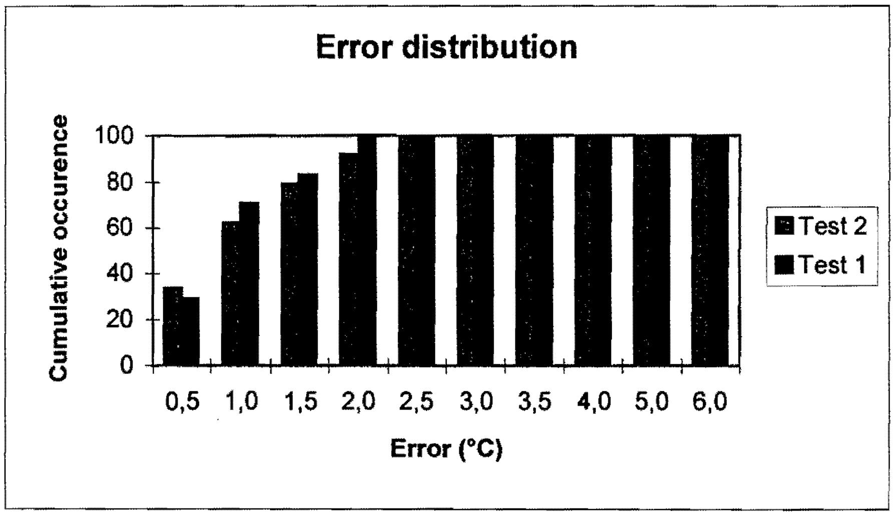




STUDY 46

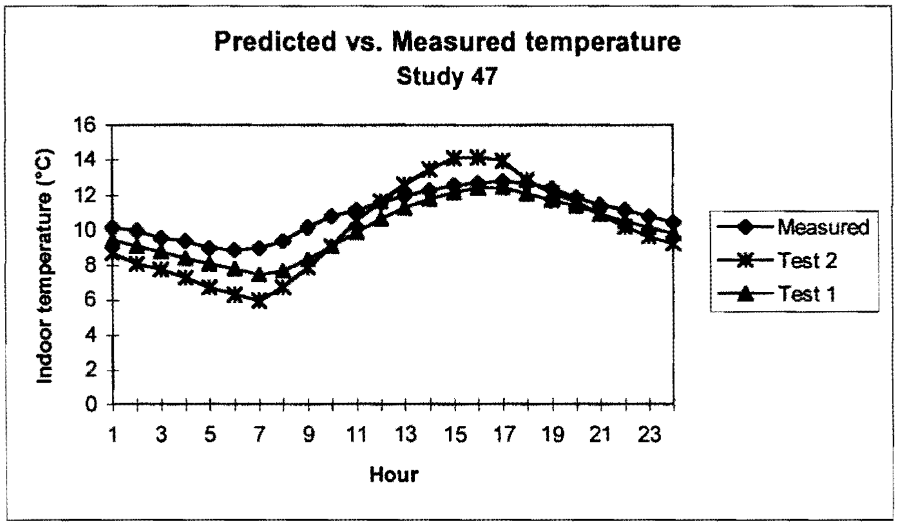
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	12.1	11.9	11.8	13	12.9	14.4	14.3
2	11.9	11.4	11.4	14	13.2	15.0	14.9
3	11.6	11.0	11.0	15	13.4	15.4	15.3
4	11.3	10.6	10.6	16	13.6	15.7	15.5
5	10.9	10.2	10.2	17	13.8	15.6	15.5
6	10.7	9.9	9.8	18	13.8	15.2	15.1
7	10.7	9.6	9.6	19	13.7	14.7	14.6
8	11.1	10.3	10.2	20	13.6	14.2	14.1
9	11.5	11.1	11.0	21	13.3	13.7	13.6
10	11.9	12.0	11.9	22	13.2	13.2	13.1
11	12.2	12.9	12.8	23	12.9	12.7	12.7
12	12.6	13.7	13.6	24	12.4	12.3	12.2

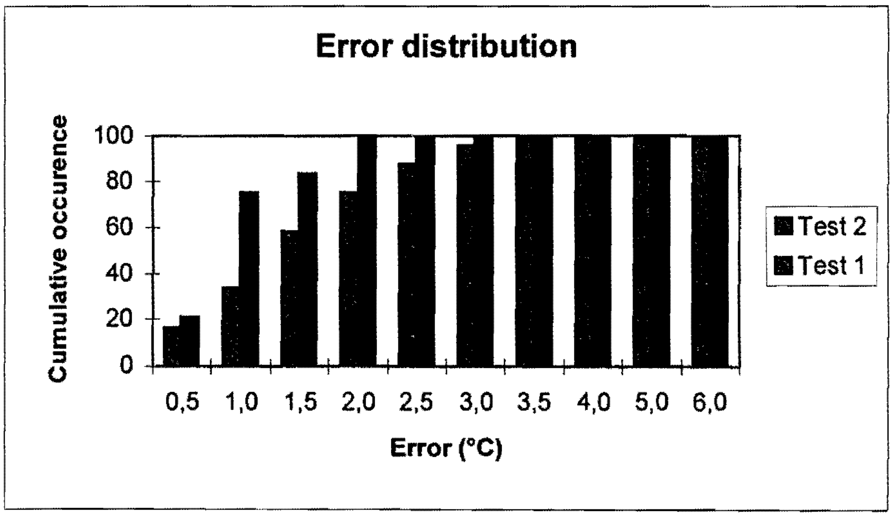




STUDY 47

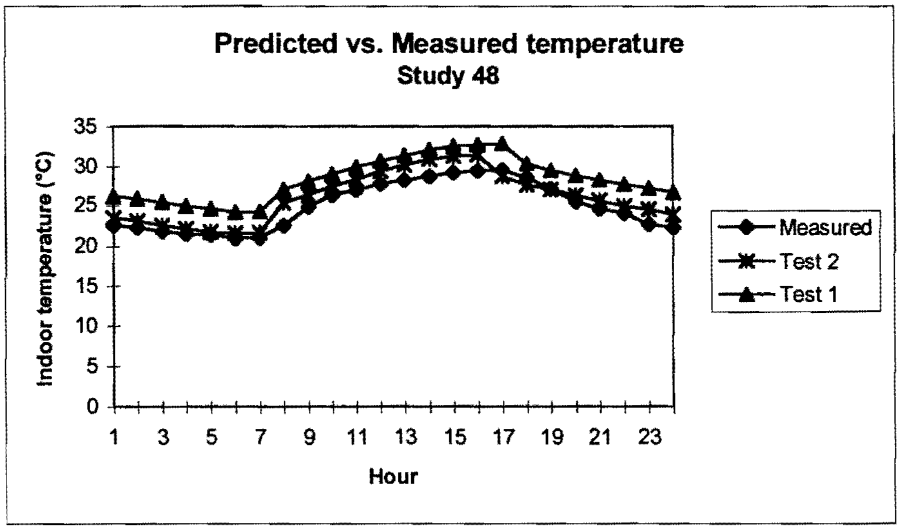
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	10.2	8.7	9.5	13	12.0	12.6	11.3
2	10.0	8.1	9.1	14	12.3	13.5	11.8
3	9.6	7.7	8.8	15	12.6	14.1	12.2
4	9.4	7.3	8.4	16	12.7	14.1	12.4
5	9.0	6.7	8.1	17	12.8	14.0	12.5
6	8.9	6.3	7.8	18	12.7	12.9	12.1
7	9.0	6.0	7.5	19	12.4	12.1	11.8
8	9.4	6.7	7.7	20	11.9	11.7	11.4
9	10.2	7.8	8.3	21	11.5	10.9	11.0
10	10.8	9.1	9.1	22	11.2	10.2	10.5
11	11.2	10.6	9.9	23	10.8	9.7	10.2
12	11.6	11.7	10.7	24	10.5	9.3	9.9

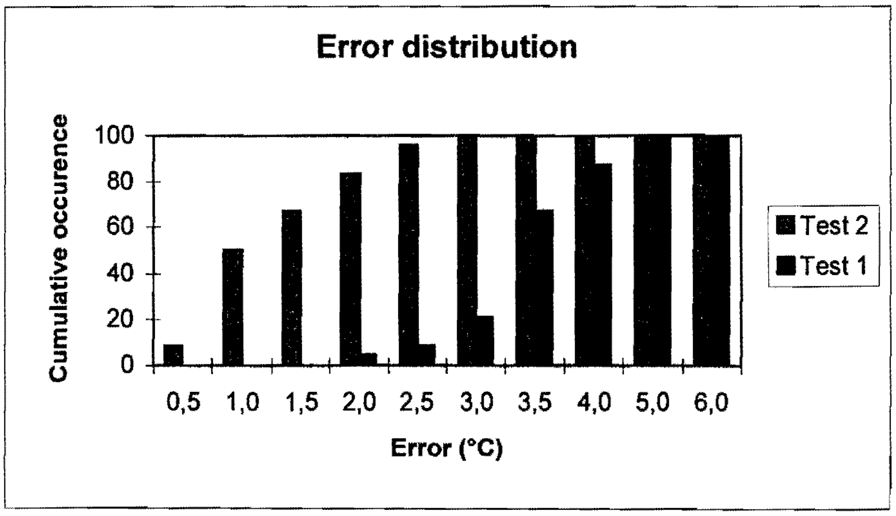




STUDY 48

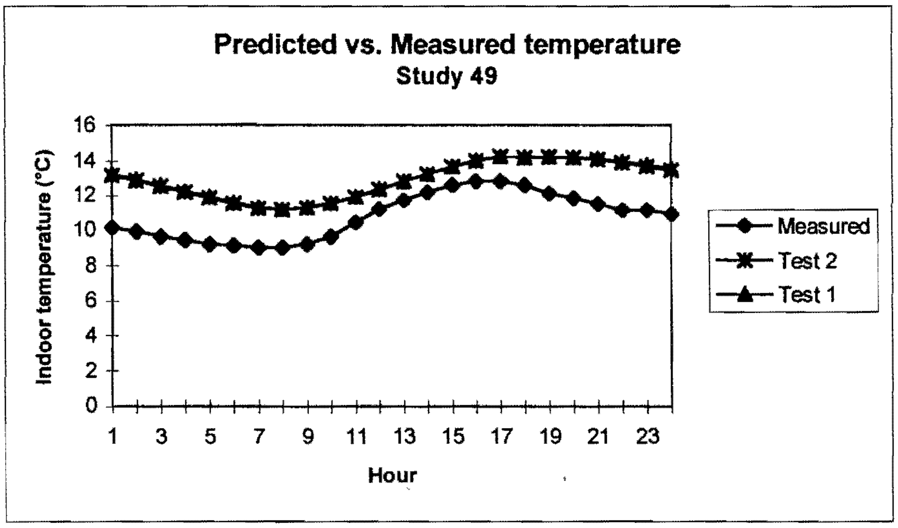
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.5	23.5	26.2	13	28.2	30.1	31.4
2	22.3	23.1	25.8	14	28.7	30.9	32.0
3	21.8	22.5	25.4	15	29.2	31.3	32.5
4	21.5	22.1	25.0	16	29.4	31.4	32.7
5	21.4	21.7	24.6	17	29.5	28.7	32.8
6	21.0	21.5	24.2	18	28.5	27.6	30.3
7	21.1	21.6	24.3	19	27.1	27.0	29.4
8	22.5	25.3	27.0	20	25.5	26.2	28.8
9	24.9	26.4	28.1	21	24.6	25.6	28.2
10	26.3	27.4	29.0	22	24.1	24.9	27.7
11	26.9	28.3	29.9	23	22.7	24.5	27.1
12	27.7	29.3	30.6	24	22.3	23.9	26.7

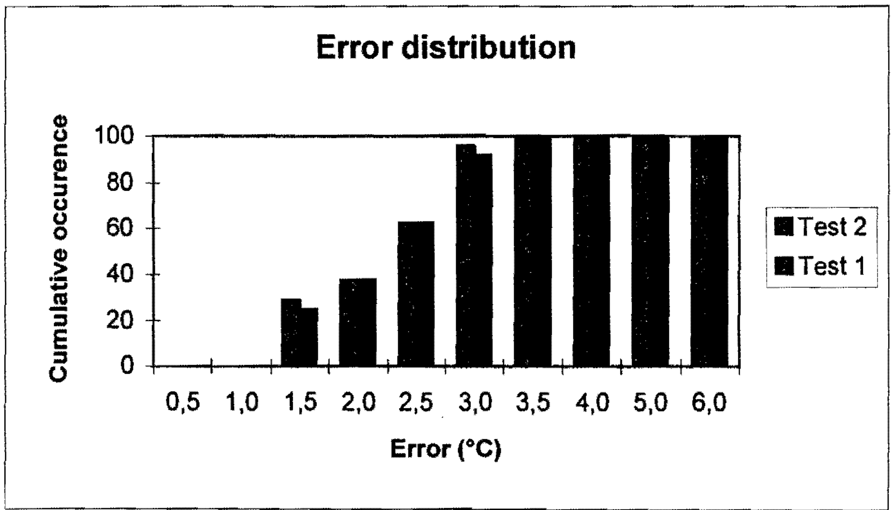




STUDY 49

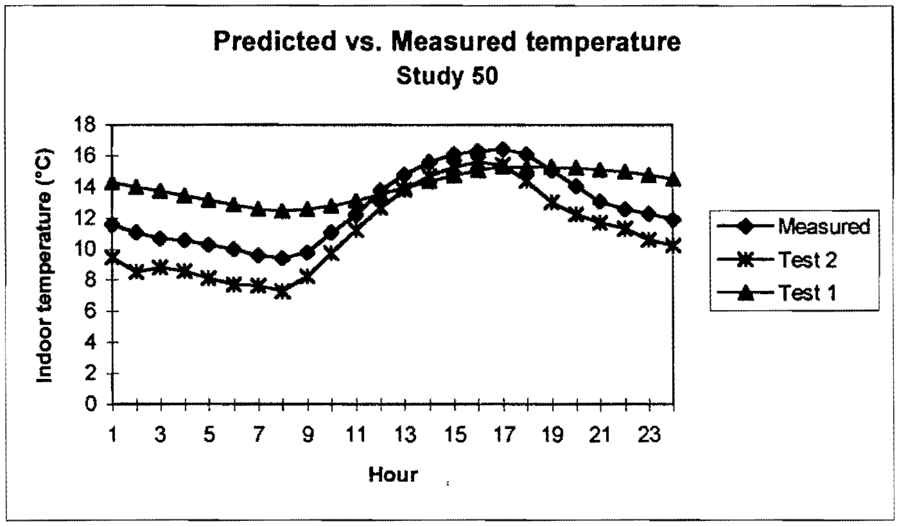
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	10.1	13.2	13.2	13	11.7	12.8	12.8
2	9.9	12.9	12.9	14	12.2	13.2	13.2
3	9.6	12.5	12.6	15	12.6	13.7	13.7
4	9.4	12.2	12.3	16	12.8	14.0	14.0
5	9.2	11.9	11.9	17	12.8	14.3	14.3
6	9.1	11.5	11.6	18	12.6	14.2	14.2
7	9.0	11.2	11.3	19	12.1	14.2	14.3
8	9.0	11.1	11.2	20	11.8	14.2	14.2
9	9.2	11.3	11.3	21	11.5	14.1	14.1
10	9.6	11.5	11.6	22	11.1	13.9	14.0
11	10.4	11.9	11.9	23	11.1	13.7	13.8
12	11.2	12.3	12.4	24	10.9	13.5	13.6

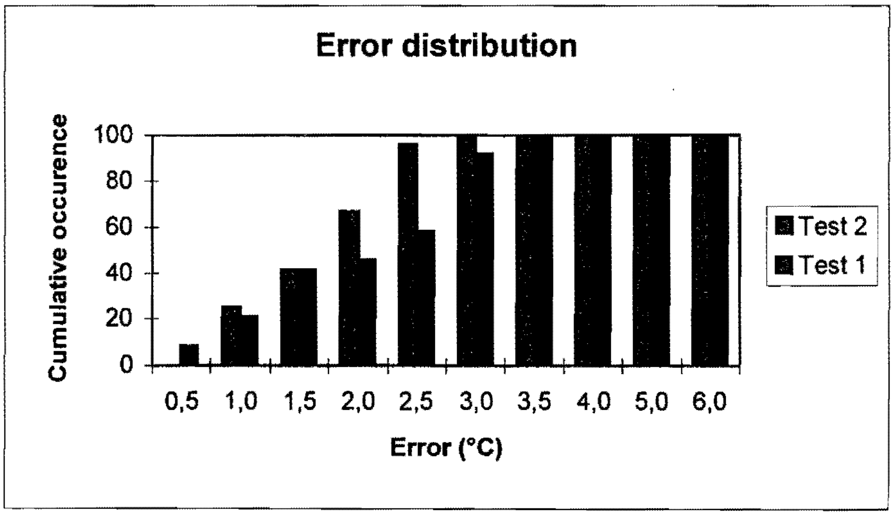




STUDY 50

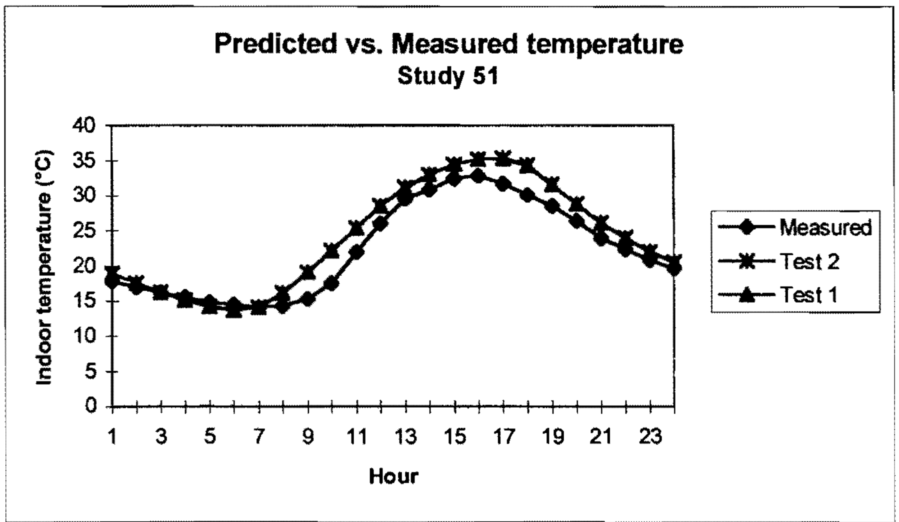
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	11.6	9.5	14.3	13	14.8	13.8	14.0
2	11.1	8.5	14.0	14	15.6	14.7	14.4
3	10.7	8.8	13.7	15	16.1	15.3	14.8
4	10.6	8.5	13.5	16	16.3	15.6	15.1
5	10.3	8.1	13.2	17	16.4	15.4	15.4
6	10.0	7.7	12.9	18	16.1	14.4	15.3
7	9.6	7.6	12.6	19	15.1	13.0	15.3
8	9.4	7.2	12.5	20	14.1	12.2	15.2
9	9.8	8.2	12.6	21	13.1	11.7	15.1
10	11.1	9.8	12.8	22	12.6	11.3	15.0
11	12.2	11.3	13.1	23	12.3	10.6	14.8
12	13.8	12.7	13.5	24	11.9	10.3	14.6

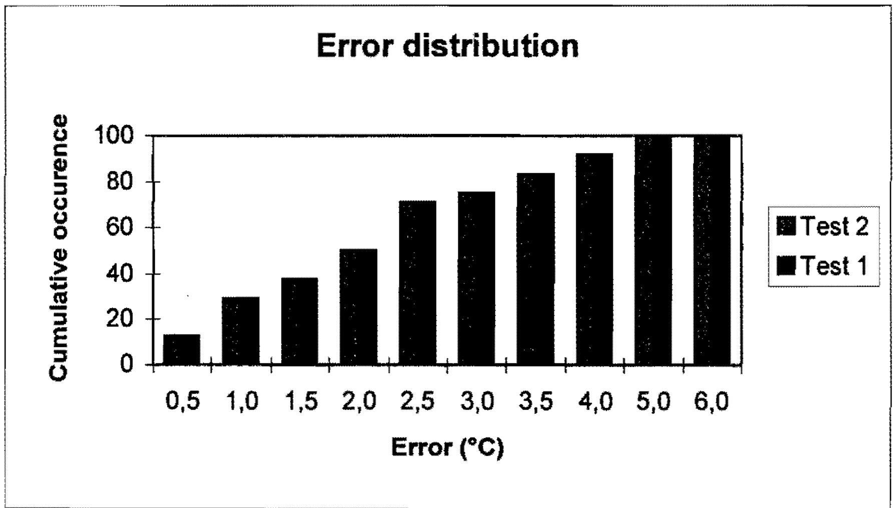




STUDY 51

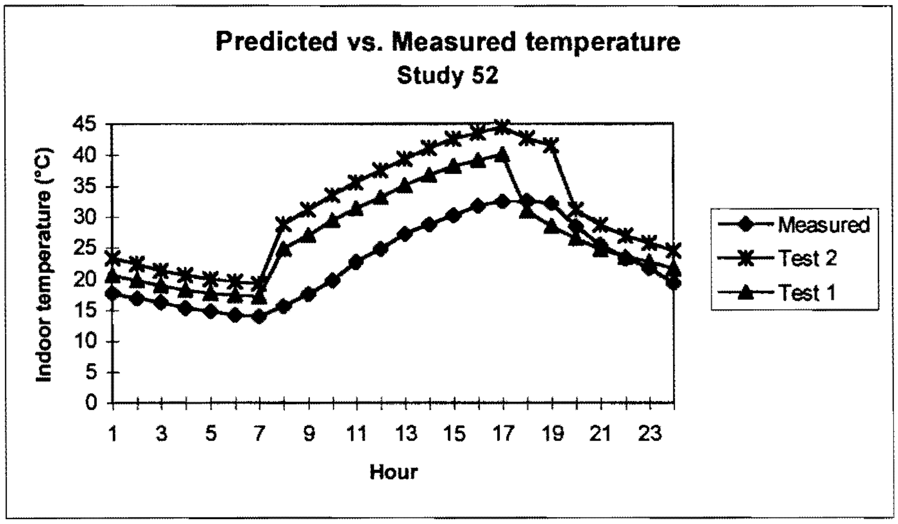
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	17.7	18.9	18.9	13	29.5	31.1	31.1
2	16.9	17.5	17.5	14	30.8	32.9	32.9
3	16.2	16.2	16.2	15	32.4	34.5	34.4
4	15.5	15.1	15.1	16	32.8	35.2	35.2
5	14.8	14.2	14.2	17	31.7	35.4	35.3
6	14.4	13.6	13.6	18	30.1	34.3	34.3
7	14.1	14.0	14.1	19	28.5	31.6	31.5
8	14.3	16.1	16.1	20	26.4	28.8	28.8
9	15.3	19.1	19.0	21	24.0	26.1	26.1
10	17.5	22.2	22.2	22	22.4	24.0	24.0
11	22.0	25.4	25.4	23	20.8	22.1	22.1
12	26.0	28.6	28.5	24	19.6	20.6	20.6

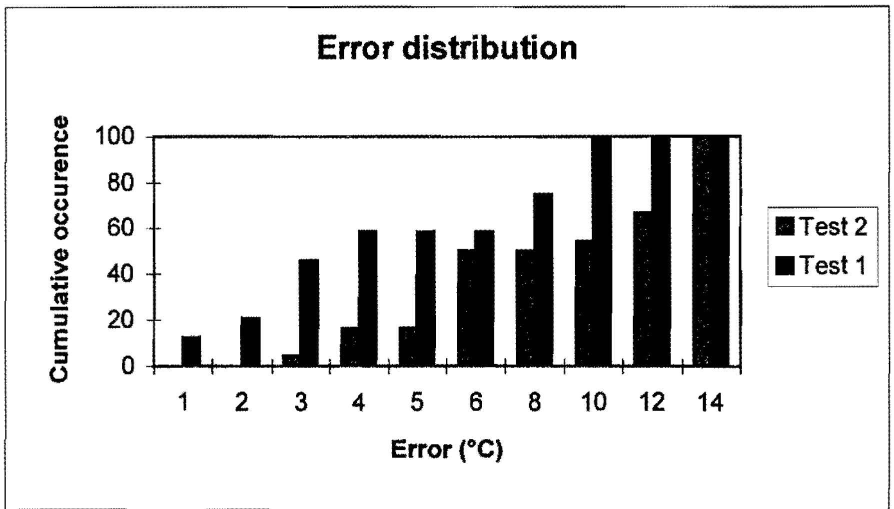




STUDY 52

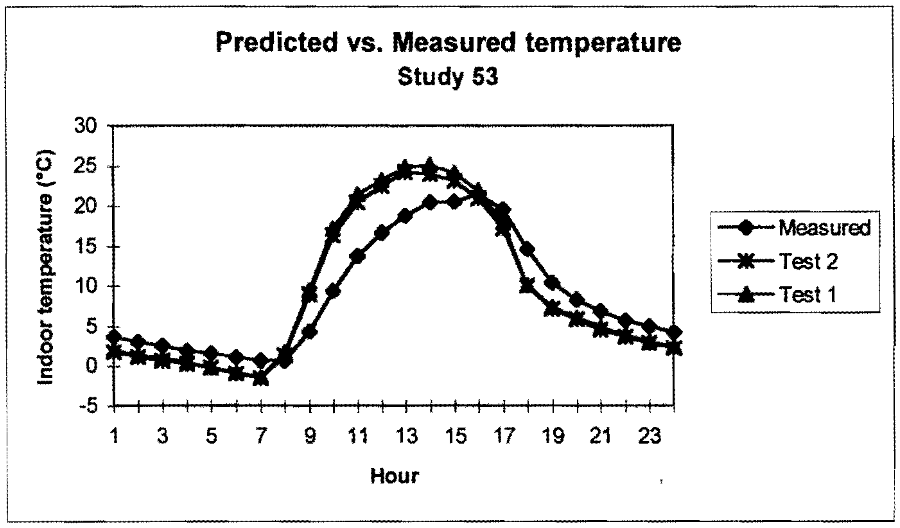
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	17.7	23.3	20.6	13	27.2	39.4	35.1
2	16.9	22.4	19.8	14	28.8	41.1	36.8
3	16.2	21.4	19.0	15	30.2	42.6	38.2
4	15.3	20.6	18.3	16	31.8	43.5	39.2
5	14.8	20.0	17.7	17	32.5	44.4	40.1
6	14.2	19.6	17.4	18	32.6	42.8	31.0
7	14.0	19.3	17.2	19	32.2	41.6	28.5
8	15.6	28.8	24.8	20	28.4	31.2	26.5
9	17.6	31.1	27.0	21	25.4	28.6	24.7
10	19.8	33.6	29.4	22	23.3	26.9	23.5
11	22.7	35.7	31.4	23	21.8	25.7	22.7
12	24.8	37.6	33.3	24	19.4	24.5	21.7

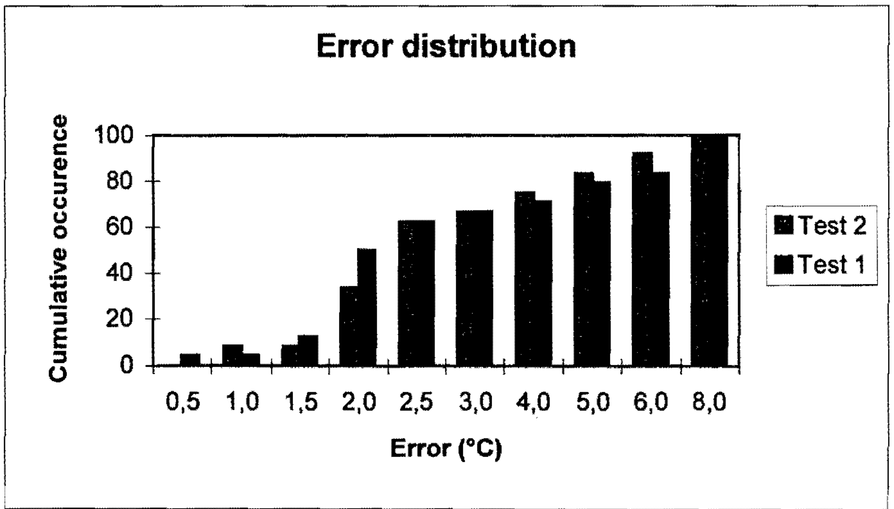




STUDY 53

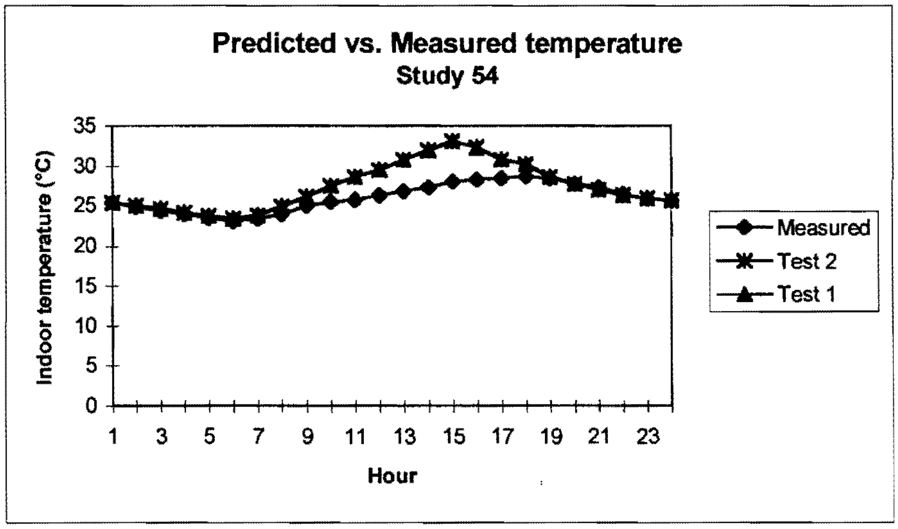
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	3.7	1.8	2.0	13	18.8	24.2	24.8
2	3.0	1.1	1.3	14	20.5	24.0	25.1
3	2.5	0.7	1.0	15	20.6	23.2	24.1
4	1.9	0.3	0.5	16	21.5	21.0	22.0
5	1.6	-0.3	-0.1	17	19.6	17.3	17.9
6	1.1	-1.0	-0.8	18	14.7	10.0	10.1
7	0.7	-1.6	-1.3	19	10.4	7.2	7.4
8	0.7	1.4	1.8	20	8.3	5.8	6.1
9	4.3	9.0	9.4	21	6.9	4.6	4.9
10	9.3	16.4	17.2	22	5.7	3.7	3.9
11	13.8	20.5	21.5	23	5.0	2.8	3.1
12	16.7	22.5	23.3	24	4.2	2.2	2.5

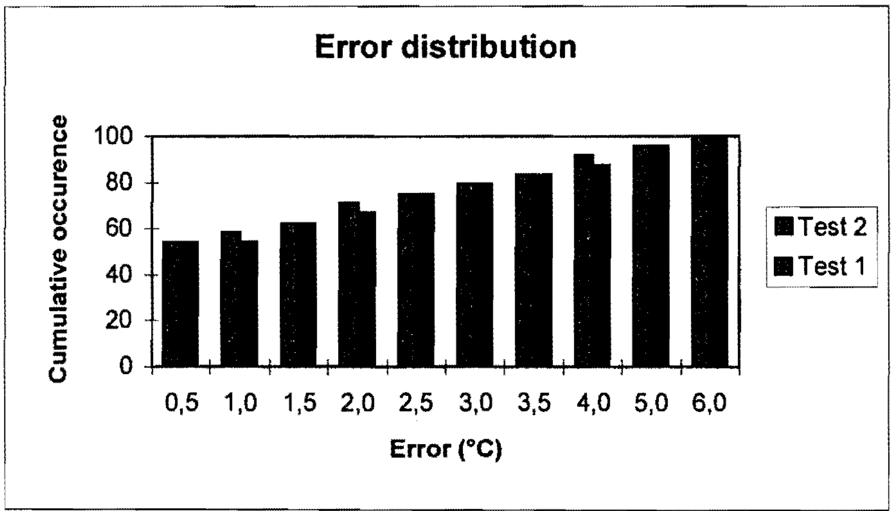




STUDY 54

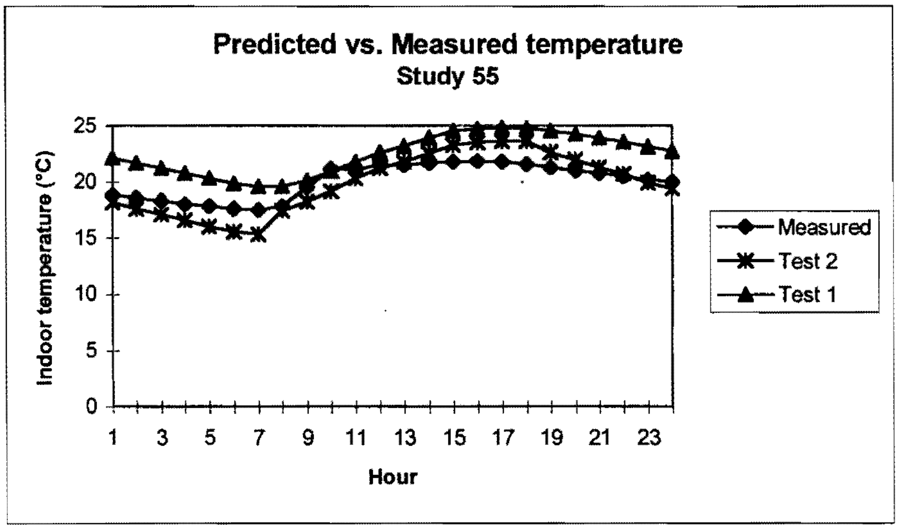
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.4	25.4	25.5	13	26.8	30.8	30.8
2	24.9	25.0	25.1	14	27.3	32.0	32.0
3	24.4	24.6	24.7	15	28.0	33.0	33.1
4	24.0	24.2	24.2	16	28.3	32.3	32.2
5	23.5	23.7	23.8	17	28.4	30.8	30.9
6	23.1	23.4	23.5	18	28.7	30.2	30.3
7	23.4	23.8	23.9	19	28.4	28.6	28.7
8	24.0	25.0	25.1	20	27.8	27.7	27.8
9	25.0	26.1	26.2	21	27.3	26.9	27.0
10	25.5	27.5	27.5	22	26.5	26.4	26.5
11	25.8	28.6	28.7	23	25.9	25.9	26.0
12	26.3	29.5	29.6	24	25.7	25.7	25.8

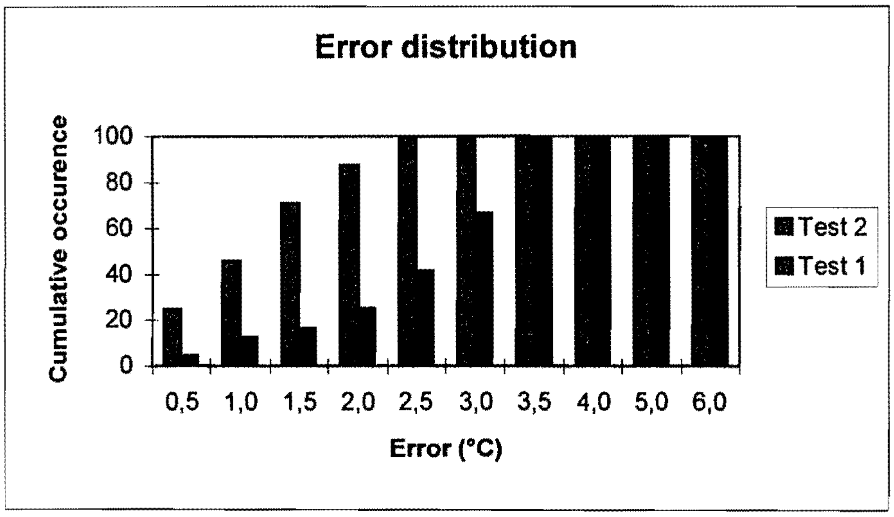




STUDY 55

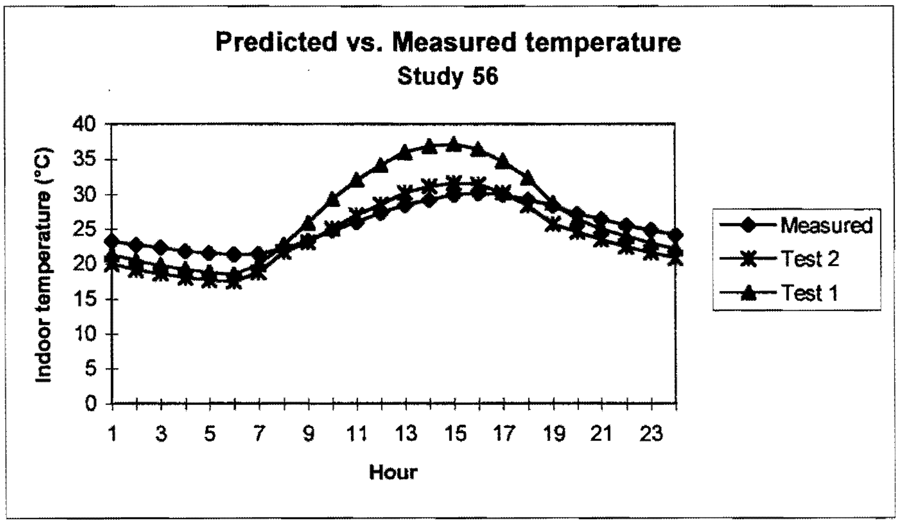
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	18.8	18.2	22.2	13	21.5	21.8	23.2
2	18.6	17.6	21.7	14	21.7	22.6	23.9
3	18.3	17.1	21.2	15	21.8	23.3	24.5
4	18	16.5	20.8	16	21.9	23.5	24.7
5	17.8	16.0	20.3	17	21.8	23.6	24.8
6	17.6	15.5	19.9	18	21.6	23.6	24.8
7	17.5	15.3	19.5	19	21.3	22.6	24.5
8	17.8	17.4	19.6	20	21	22.0	24.3
9	19.5	18.3	20.1	21	20.8	21.3	23.9
10	21.2	19.2	21.0	22	20.5	20.7	23.6
11	21.1	20.3	21.8	23	20.2	19.9	23.2
12	21.5	21.3	22.6	24	20	19.4	22.7

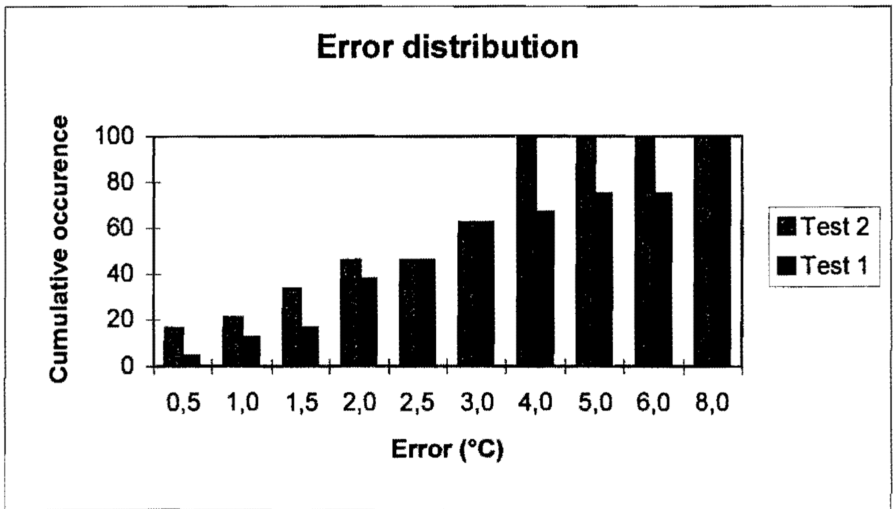




STUDY 56

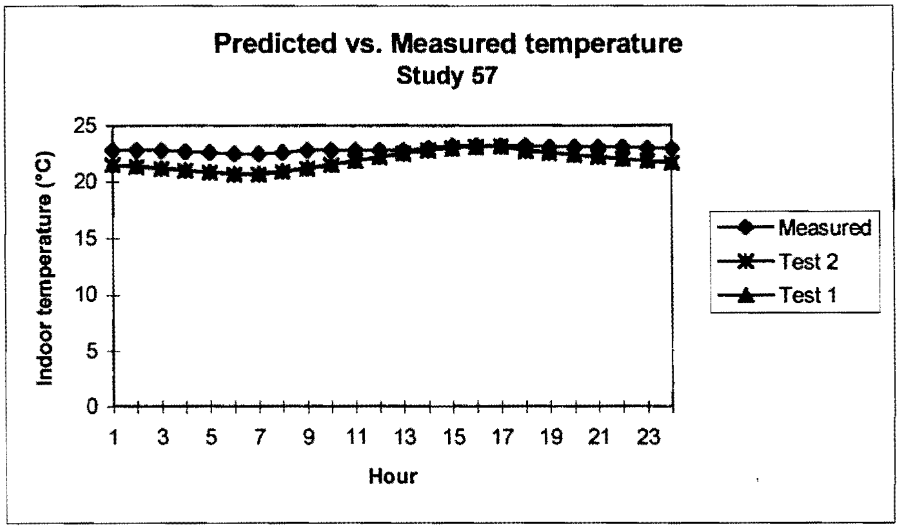
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.2	20.0	21.3	13	28.4	30.2	36.0
2	22.7	19.2	20.5	14	29.2	31.1	36.9
3	22.3	18.6	19.8	15	29.9	31.6	37.1
4	21.8	18.1	19.3	16	30.1	31.4	36.4
5	21.5	17.7	18.8	17	29.9	30.2	34.8
6	21.3	17.5	18.6	18	29.2	28.4	32.4
7	21.4	18.8	19.9	19	28.3	25.6	28.8
8	22.1	21.7	22.7	20	27.1	24.5	26.4
9	23.2	23.1	25.9	21	26.4	23.5	25.0
10	24.7	25.0	29.2	22	25.5	22.5	23.9
11	25.9	27.0	32.1	23	24.8	21.6	22.9
12	27.3	28.5	34.2	24	24.1	20.8	22.1

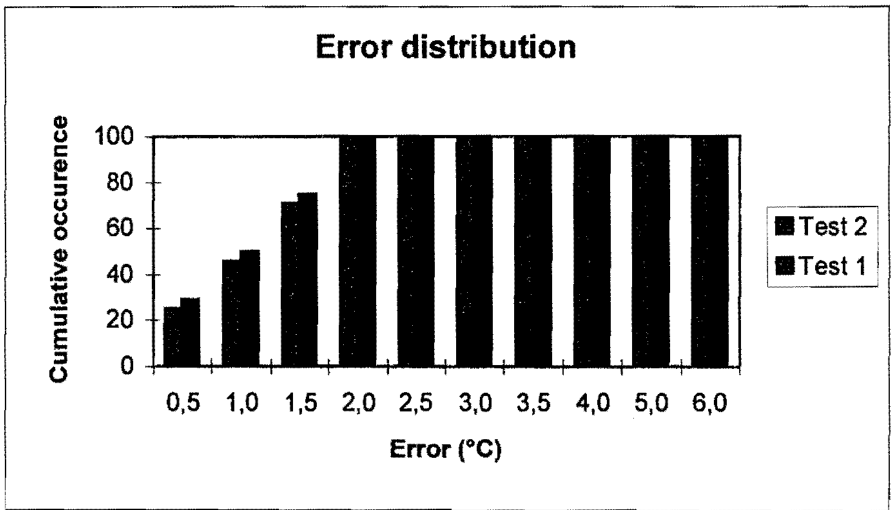




STUDY 57

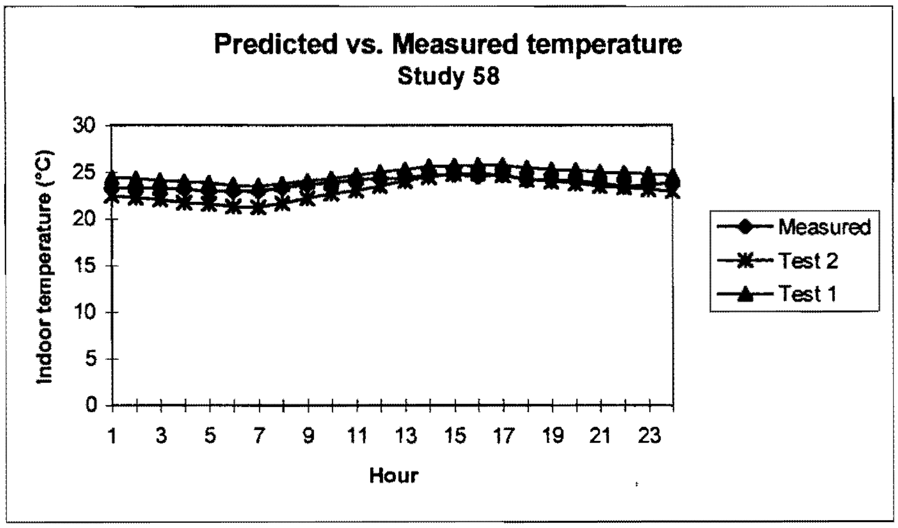
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.8	21.5	21.6	13	22.8	22.5	22.6
2	22.8	21.4	21.5	14	23.0	22.8	22.9
3	22.8	21.2	21.3	15	23.2	23.0	23.0
4	22.7	21.0	21.1	16	23.2	23.1	23.2
5	22.6	20.9	21.0	17	23.2	23.1	23.2
6	22.5	20.7	20.8	18	23.2	22.8	22.9
7	22.5	20.7	20.8	19	23.1	22.6	22.7
8	22.6	20.9	21.0	20	23.1	22.4	22.5
9	22.8	21.2	21.3	21	23.1	22.2	22.3
10	22.8	21.5	21.6	22	23.1	22.0	22.1
11	22.8	21.9	22.0	23	23.0	21.9	22.0
12	22.8	22.2	22.3	24	23.0	21.7	21.8

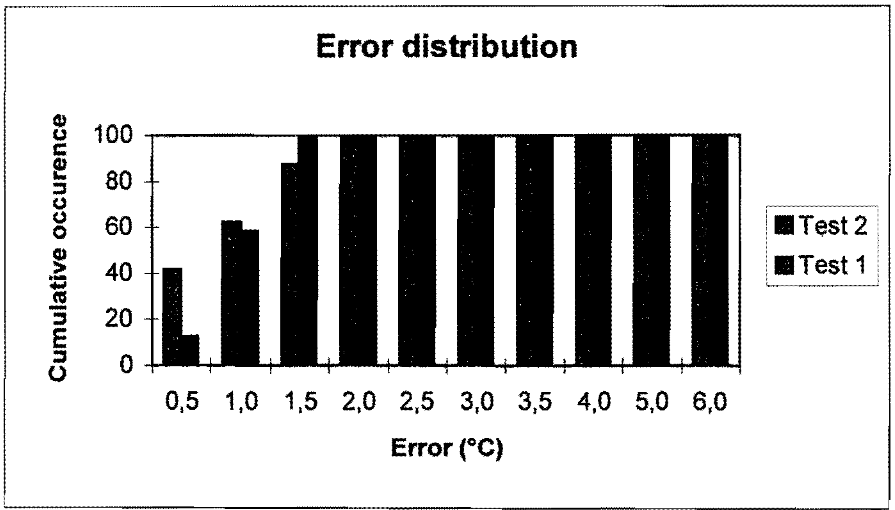




STUDY 58

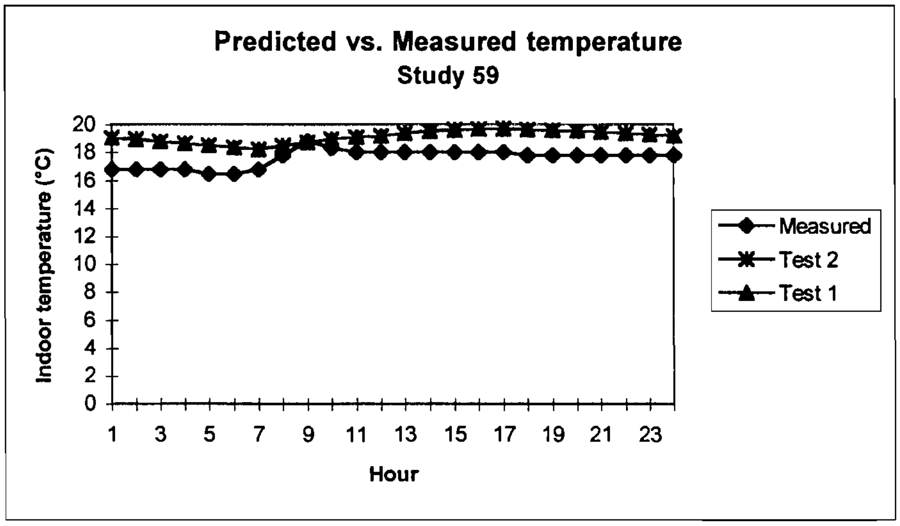
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.3	22.5	24.4	13	24.3	24.1	25.3
2	23.3	22.3	24.3	14	24.7	24.5	25.6
3	23.3	22.1	24.1	15	24.7	24.8	25.7
4	23.2	21.7	23.9	16	24.5	24.9	25.8
5	23.0	21.6	23.8	17	24.7	24.6	25.8
6	23.0	21.3	23.6	18	24.2	24.2	25.5
7	23.0	21.2	23.6	19	24.2	24.0	25.3
8	23.3	21.7	23.7	20	24.0	23.8	25.2
9	23.7	22.2	24.0	21	23.8	23.6	25.0
10	23.8	22.7	24.3	22	23.5	23.4	24.9
11	24.2	23.1	24.6	23	23.7	23.2	24.8
12	24.3	23.6	25.0	24	23.8	23.0	24.6

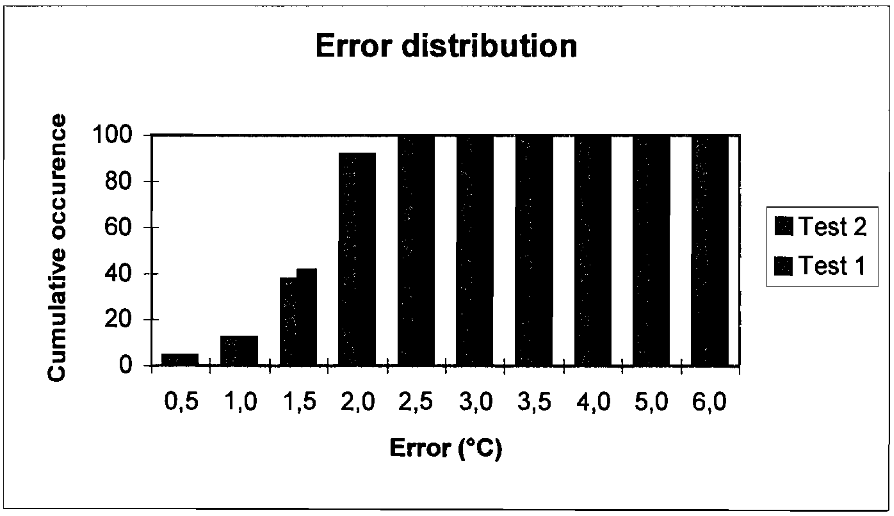




STUDY 59

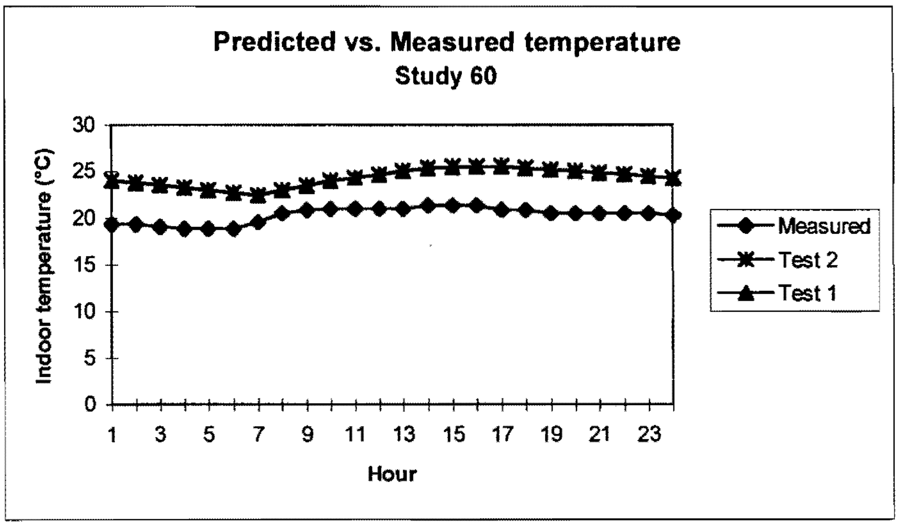
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	16.8	19.0	19.0	13	18.0	19.4	19.3
2	16.8	18.9	18.9	14	18.0	19.5	19.5
3	16.8	18.8	18.8	15	18.0	19.6	19.6
4	16.8	18.6	18.6	16	18.0	19.7	19.7
5	16.5	18.5	18.5	17	18.0	19.7	19.7
6	16.5	18.3	18.3	18	17.8	19.7	19.6
7	16.8	18.2	18.2	19	17.8	19.6	19.6
8	17.8	18.5	18.4	20	17.8	19.5	19.5
9	18.8	18.7	18.7	21	17.8	19.5	19.4
10	18.3	18.9	18.9	22	17.8	19.4	19.4
11	18.0	19.1	19.1	23	17.8	19.3	19.3
12	18.0	19.2	19.2	24	17.8	19.2	19.2

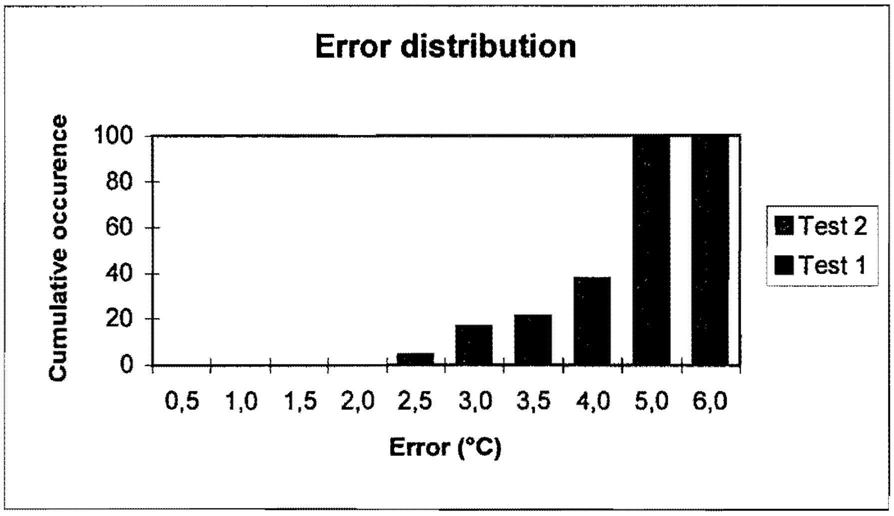




STUDY 60

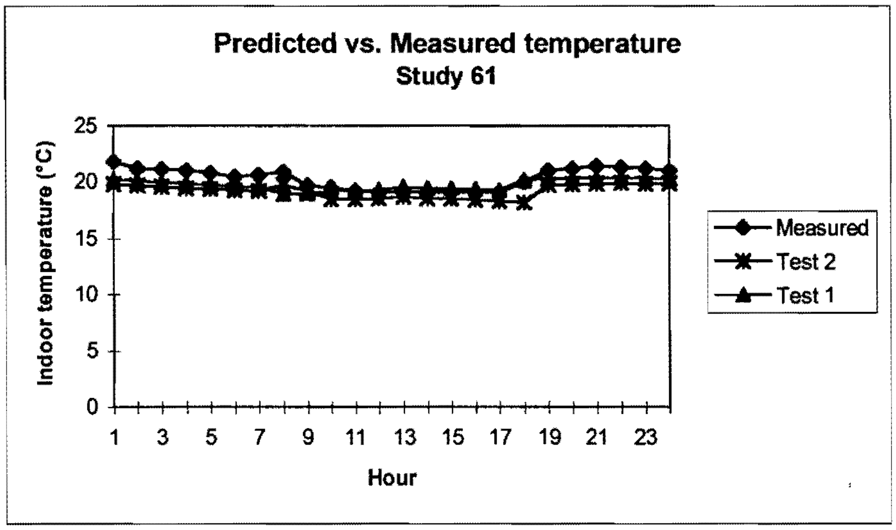
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	19.3	24.0	24.0	13	21.0	25.1	25.0
2	19.3	23.8	23.7	14	21.3	25.4	25.3
3	19.0	23.5	23.4	15	21.3	25.5	25.5
4	18.8	23.3	23.2	16	21.3	25.5	25.5
5	18.8	23.0	22.9	17	20.8	25.6	25.5
6	18.8	22.7	22.6	18	20.8	25.3	25.3
7	19.5	22.5	22.4	19	20.5	25.2	25.1
8	20.5	23.0	22.9	20	20.5	25.1	25.0
9	20.8	23.5	23.4	21	20.5	24.9	24.8
10	21.0	24.0	23.9	22	20.5	24.7	24.6
11	21.0	24.3	24.3	23	20.5	24.5	24.4
12	21.0	24.7	24.6	24	20.3	24.3	24.2

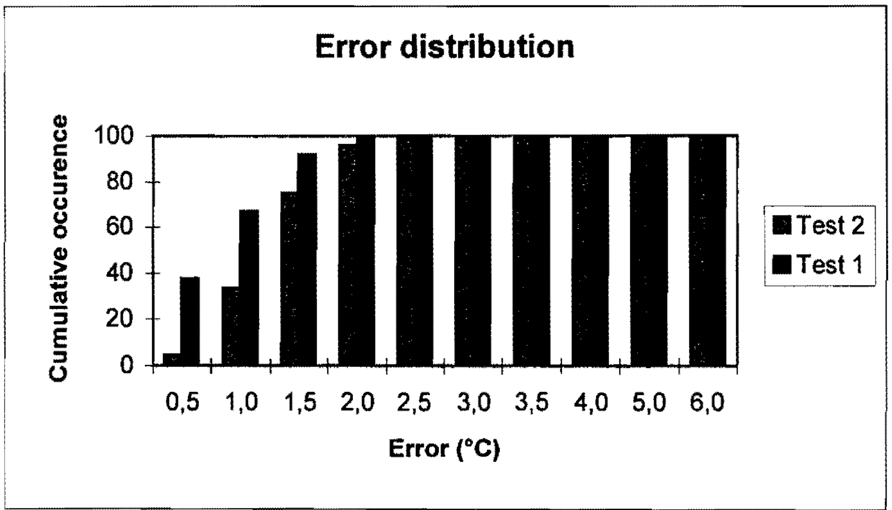




STUDY 61

Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.8	19.8	20.2	13	19.1	18.7	19.6
2	21.2	19.7	20.1	14	19.1	18.5	19.5
3	21.1	19.6	20.0	15	19.1	18.5	19.4
4	21.0	19.5	19.9	16	19.1	18.4	19.4
5	20.8	19.4	19.7	17	19.1	18.3	19.3
6	20.4	19.3	19.6	18	20.0	18.2	20.1
7	20.6	19.2	19.6	19	21.0	19.7	20.3
8	20.9	19.7	18.9	20	21.2	19.8	20.3
9	19.7	19.2	19.0	21	21.4	19.9	20.3
10	19.5	18.5	19.2	22	21.3	19.9	20.4
11	19.2	18.5	19.3	23	21.2	19.9	20.3
12	19.1	18.5	19.3	24	21.0	19.8	20.3





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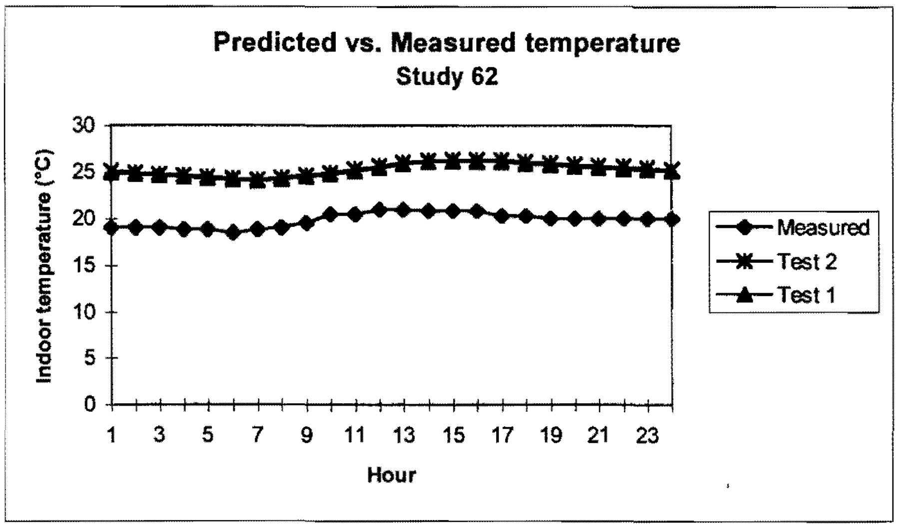
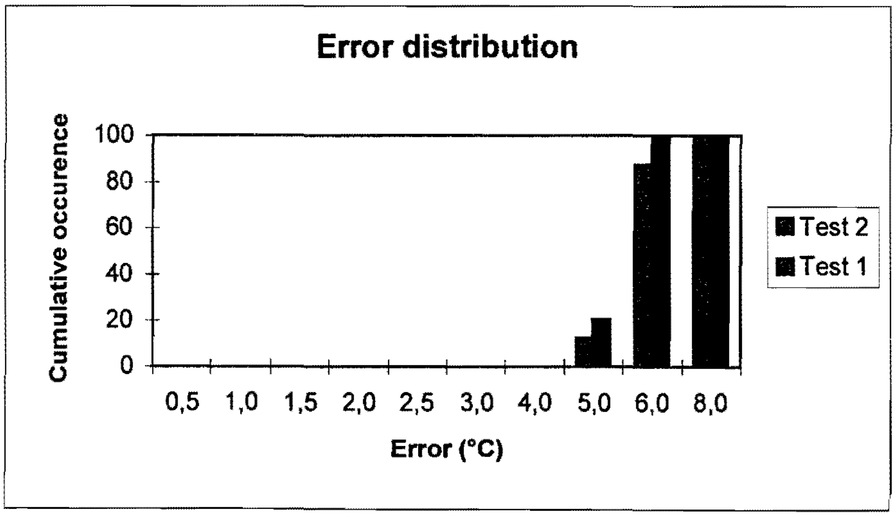
STUDY 62

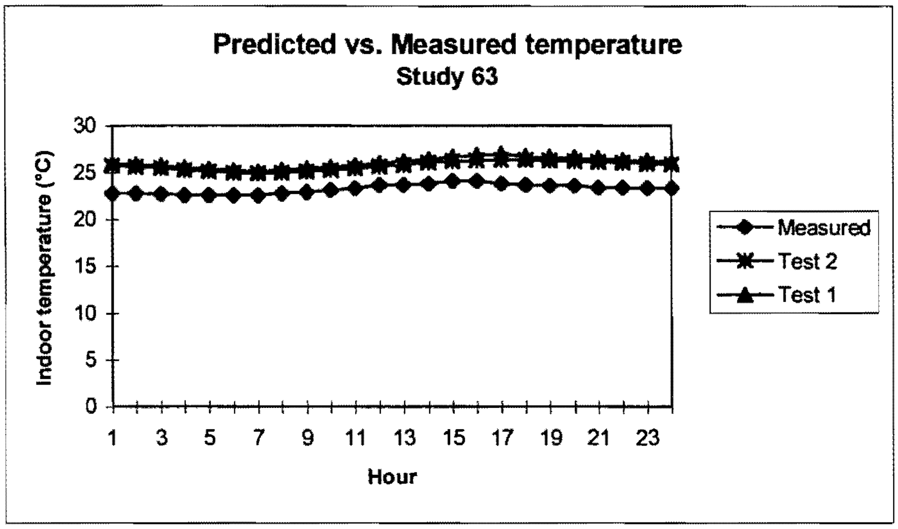
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	19.0	25.2	25.0	13	21.0	26.1	25.9
2	19.0	25.0	24.8	14	20.8	26.3	26.1
3	19.0	24.9	24.6	15	20.8	26.4	26.2
4	18.8	24.7	24.5	16	20.8	26.3	26.1
5	18.8	24.6	24.3	17	20.3	26.3	26.1
6	18.5	24.4	24.2	18	20.3	26.1	25.9
7	18.8	24.3	24.0	19	20.0	26.0	25.8
8	19.0	24.4	24.2	20	20.0	25.9	25.6
9	19.5	24.7	24.5	21	20.0	25.7	25.5
10	20.5	25.0	24.8	22	20.0	25.6	25.4
11	20.5	25.3	25.1	23	20.0	25.5	25.3
12	21.0	25.7	25.5	24	20.0	25.3	25.1

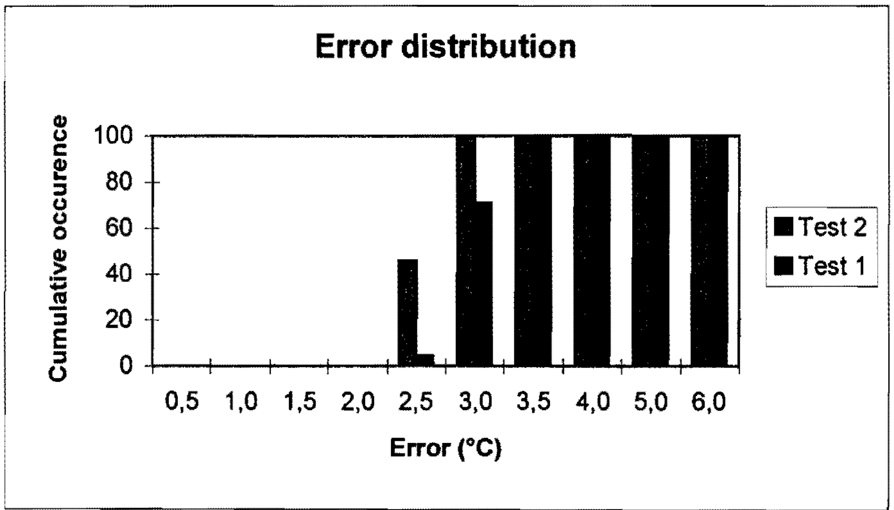




STUDY 63

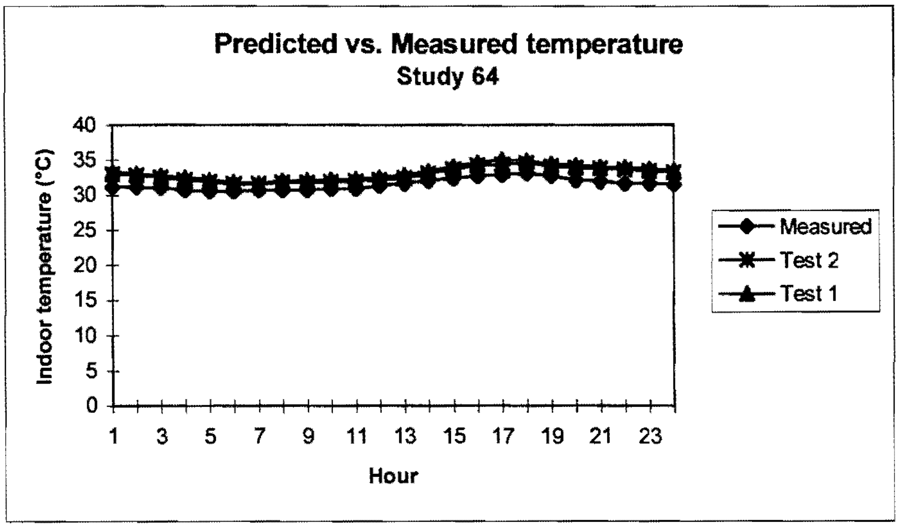
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.8	25.7	26.0	13	23.7	25.9	26.3
2	22.8	25.6	25.9	14	23.8	26.1	26.4
3	22.7	25.5	25.7	15	24.1	26.3	26.7
4	22.6	25.3	25.6	16	24.1	26.4	26.9
5	22.6	25.2	25.4	17	23.8	26.4	27.0
6	22.6	25.0	25.3	18	23.7	26.4	26.8
7	22.6	24.9	25.2	19	23.6	26.3	26.7
8	22.8	25.0	25.4	20	23.6	26.3	26.6
9	22.9	25.2	25.5	21	23.4	26.2	26.5
10	23.1	25.3	25.6	22	23.4	26.1	26.4
11	23.3	25.5	25.8	23	23.3	26.0	26.3
12	23.7	25.7	26.1	24	23.3	25.9	26.2

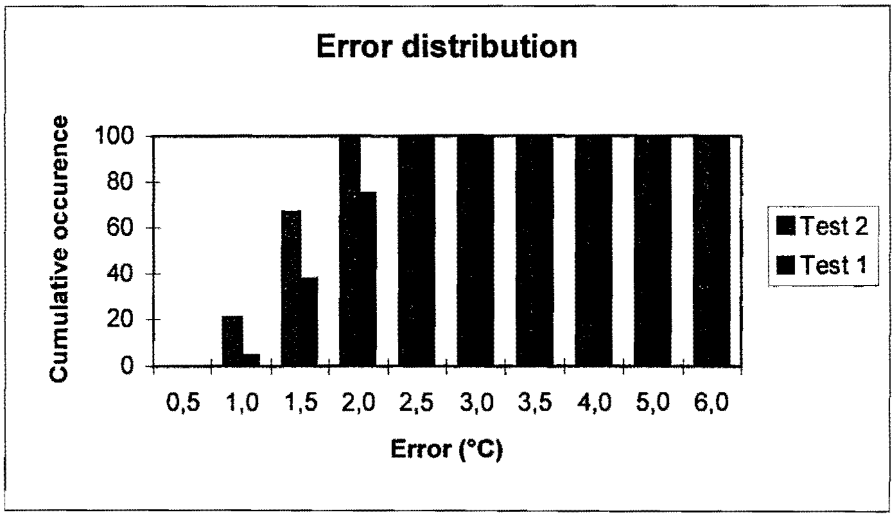




STUDY 64

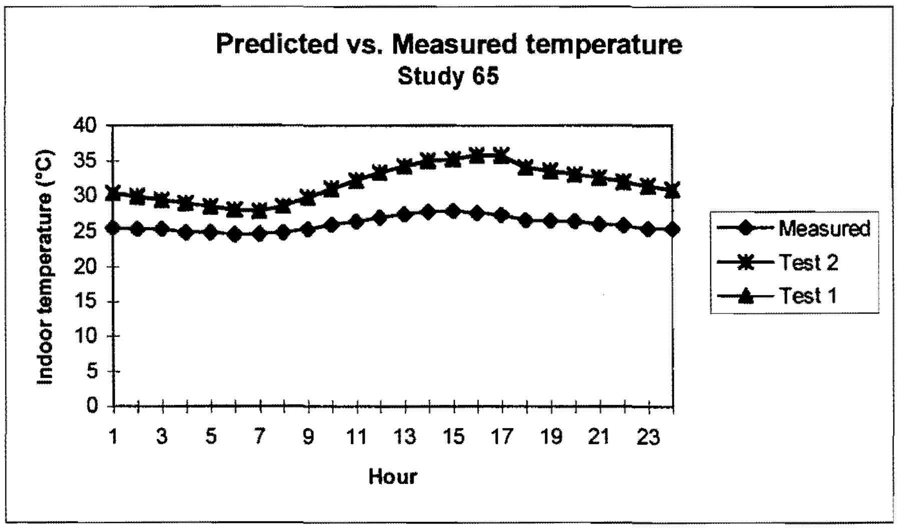
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	31.2	33.0	33.3	13	31.7	32.4	32.9
2	31.2	32.7	33.0	14	32.0	33.1	33.5
3	31.1	32.5	32.8	15	32.4	33.7	34.1
4	30.7	32.2	32.5	16	32.7	34.3	34.6
5	30.6	31.9	32.2	17	32.9	34.4	35.1
6	30.6	31.6	31.9	18	33.1	34.5	34.9
7	30.7	31.6	31.7	19	32.7	34.1	34.4
8	30.7	31.7	32.0	20	32.1	33.9	34.3
9	30.7	31.8	32.1	21	31.9	33.8	34.1
10	30.9	31.9	32.2	22	31.7	33.6	34.0
11	30.9	32.0	32.4	23	31.7	33.5	33.8
12	31.4	32.2	32.5	24	31.6	33.2	33.5

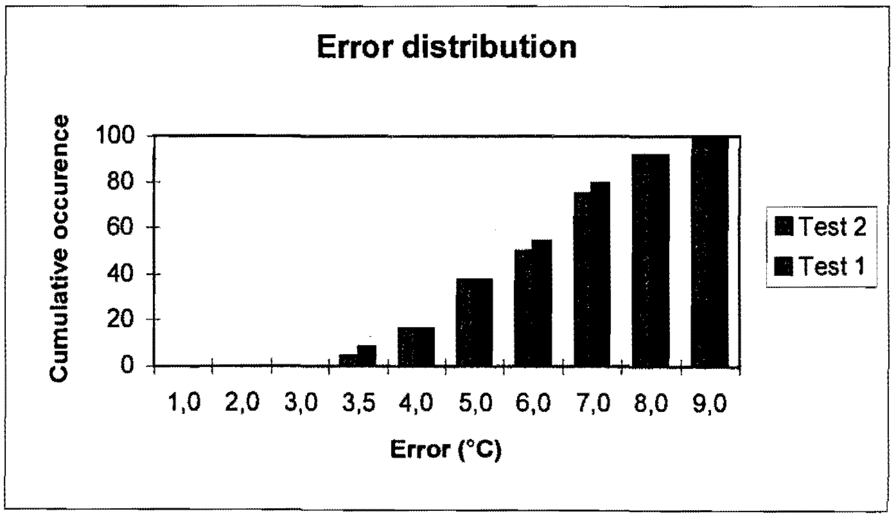




STUDY 65

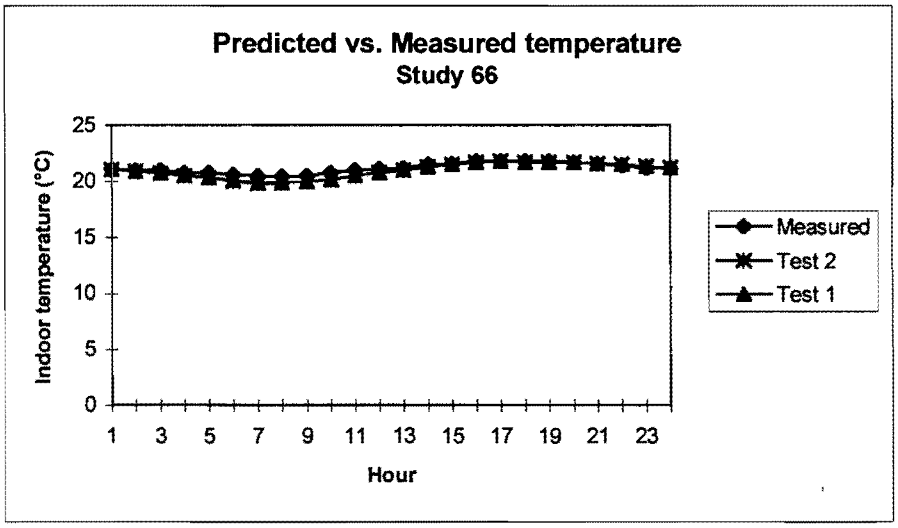
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.5	30.4	30.3	13	27.4	34.3	34.2
2	25.3	30.0	29.9	14	27.8	35.1	34.9
3	25.3	29.5	29.4	15	27.9	35.3	35.2
4	24.8	29.0	28.9	16	27.6	35.9	35.7
5	24.8	28.5	28.4	17	27.3	35.8	35.7
6	24.5	28.0	27.9	18	26.6	34.1	34.0
7	24.6	27.8	27.8	19	26.5	33.6	33.5
8	24.8	28.6	28.5	20	26.4	33.1	33.0
9	25.3	29.8	29.7	21	26.0	32.6	32.5
10	25.9	31.1	31.0	22	25.8	32.0	31.9
11	26.4	32.2	32.2	23	25.4	31.5	31.4
12	26.9	33.3	33.2	24	25.4	31.0	30.8

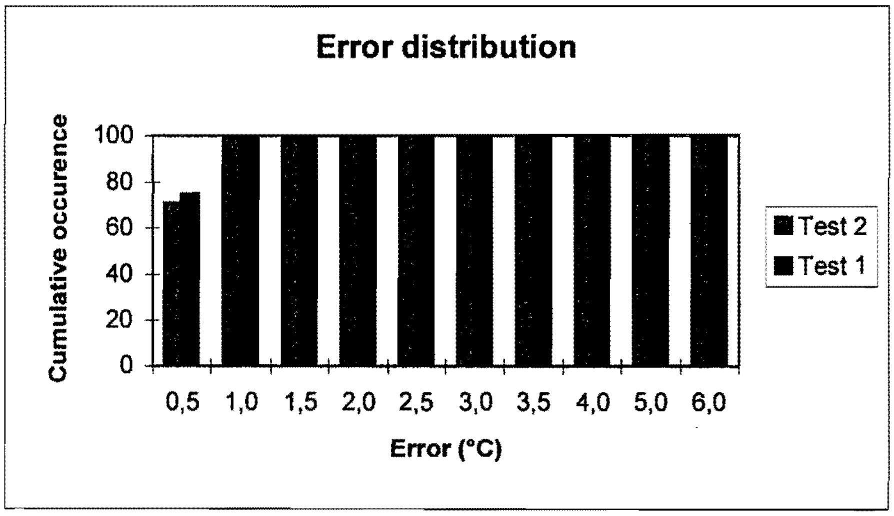




STUDY 66

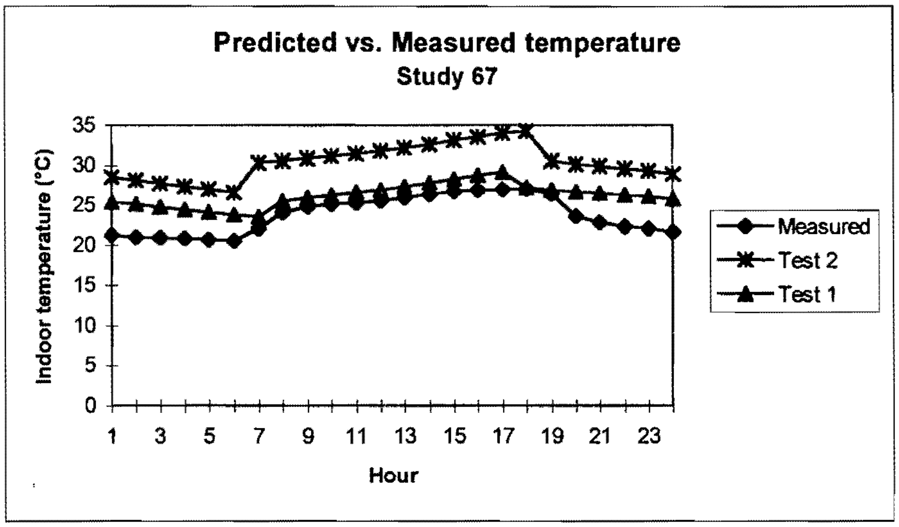
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.1	21.1	21.1	13	21.2	21.0	21.0
2	21.0	20.9	20.9	14	21.5	21.3	21.3
3	21.0	20.7	20.7	15	21.6	21.5	21.6
4	20.8	20.5	20.5	16	21.8	21.7	21.7
5	20.8	20.3	20.3	17	21.8	21.8	21.8
6	20.6	20.0	20.1	18	21.8	21.7	21.7
7	20.5	19.8	19.9	19	21.8	21.7	21.7
8	20.4	19.9	19.9	20	21.7	21.7	21.7
9	20.5	20.0	20.0	21	21.6	21.6	21.6
10	20.8	20.1	20.2	22	21.4	21.5	21.5
11	21.0	20.5	20.5	23	21.2	21.4	21.4
12	21.1	20.8	20.8	24	21.2	21.2	21.3

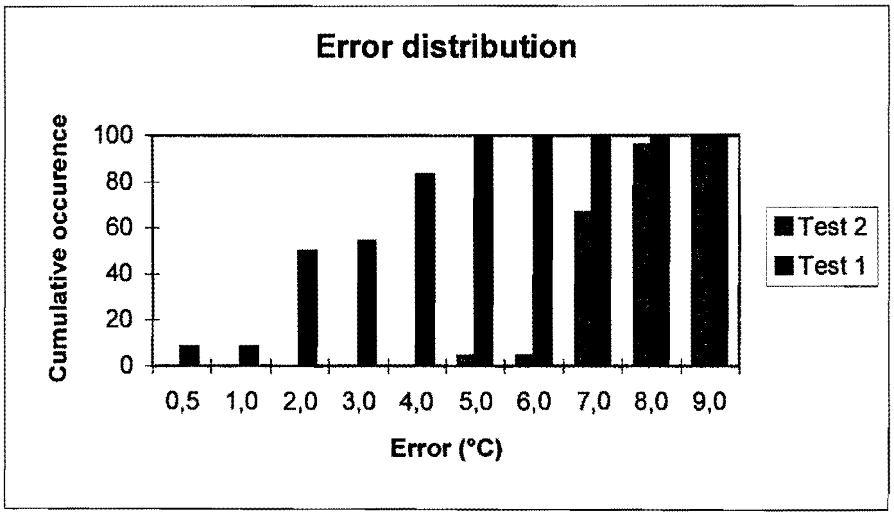




STUDY 67

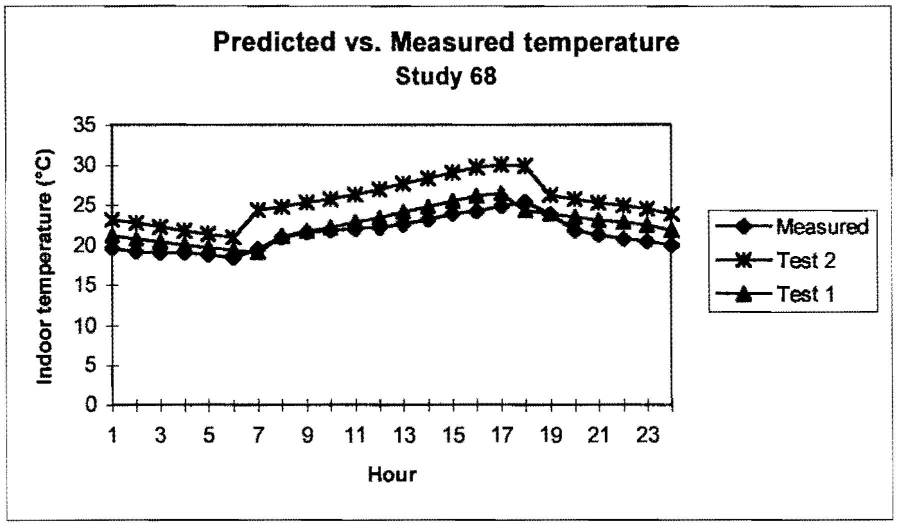
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.2	28.5	25.4	13	25.9	32.2	27.3
2	21.0	28.1	25.1	14	26.3	32.6	27.8
3	20.9	27.7	24.8	15	26.7	33.1	28.3
4	20.8	27.3	24.4	16	26.9	33.6	28.7
5	20.7	27.0	24.1	17	27.0	34.0	29.2
6	20.5	26.6	23.8	18	27.1	34.3	27.2
7	22.0	30.3	23.5	19	26.4	30.5	26.9
8	24.1	30.6	25.5	20	23.6	30.2	26.7
9	24.8	30.9	25.9	21	22.8	29.9	26.5
10	25.1	31.1	26.2	22	22.3	29.6	26.3
11	25.3	31.4	26.6	23	22.0	29.3	26.1
12	25.5	31.8	26.9	24	21.6	28.9	25.7

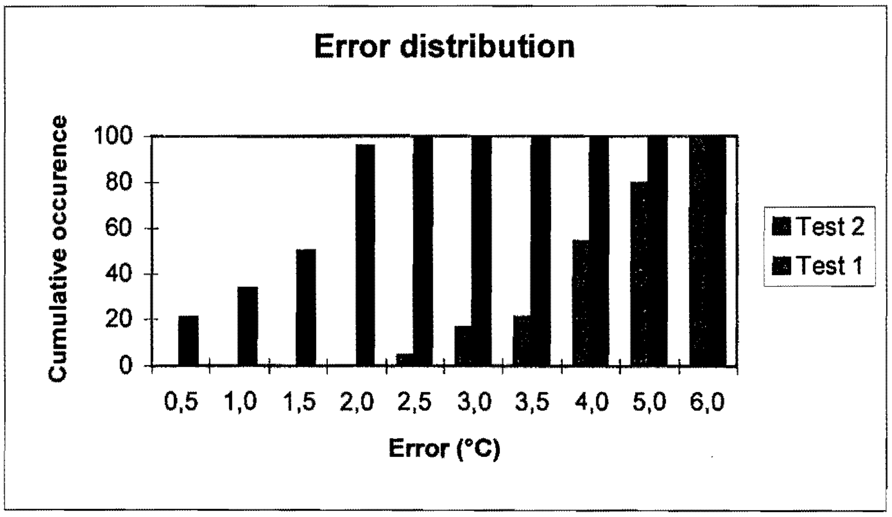




STUDY 68

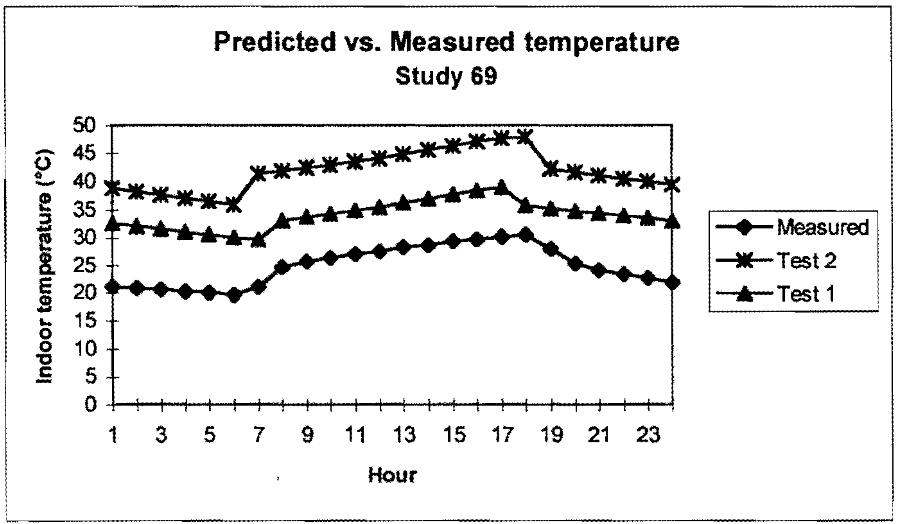
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	19.6	23.2	21.3	13	22.6	27.7	24.2
2	19.2	22.8	20.9	14	23.2	28.3	24.8
3	19.0	22.3	20.5	15	23.9	29.1	25.6
4	19.0	21.8	20.0	16	24.2	29.7	26.2
5	18.8	21.4	19.7	17	24.9	30.1	26.5
6	18.4	21.0	19.3	18	25.4	29.9	24.3
7	19.5	24.4	19.1	19	23.9	26.3	23.9
8	21.0	24.8	21.1	20	21.9	25.7	23.5
9	21.6	25.4	21.8	21	21.3	25.3	23.1
10	21.9	25.8	22.2	22	20.8	24.9	22.8
11	22.0	26.4	22.8	23	20.5	24.6	22.5
12	22.2	27.0	23.4	24	20.0	23.9	21.9

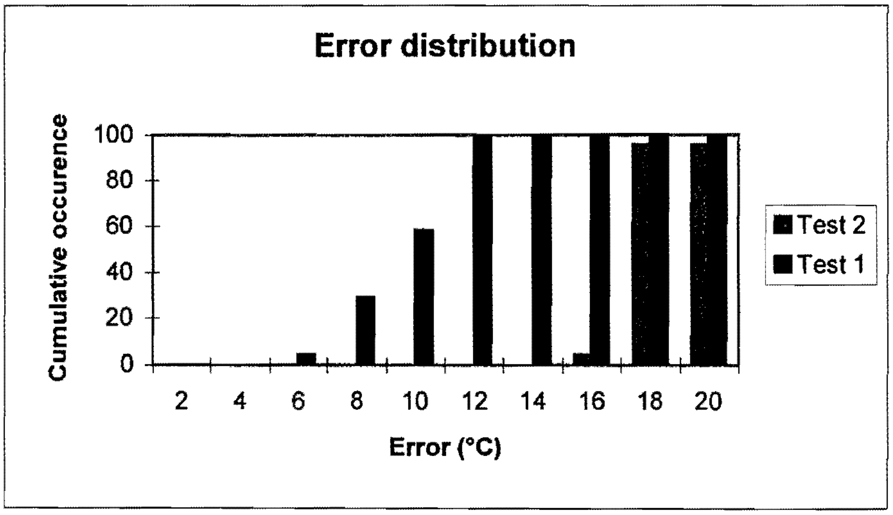




STUDY 69

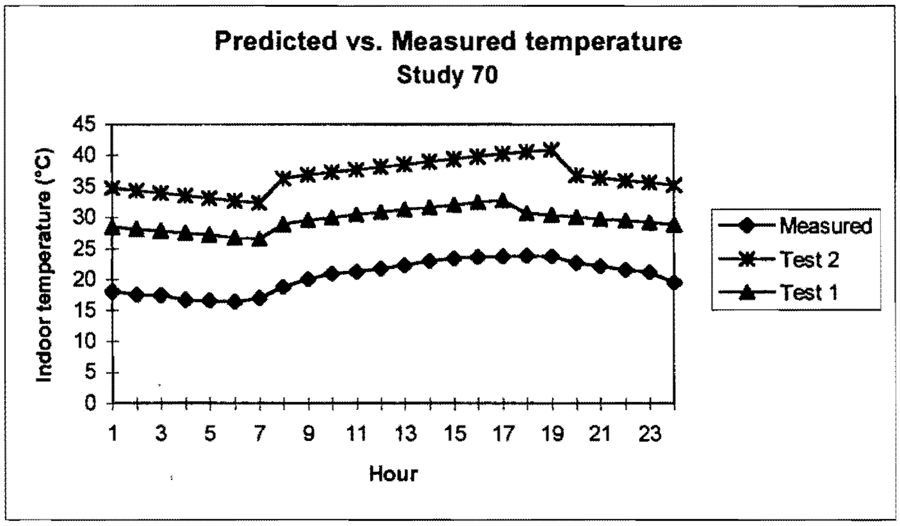
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.1	38.8	32.5	13	28.3	44.8	36.2
2	20.8	38.2	32.0	14	28.7	45.6	36.9
3	20.6	37.6	31.5	15	29.4	46.3	37.7
4	20.3	37.0	31.1	16	29.7	47.1	38.5
5	20.0	36.5	30.6	17	30.2	47.6	39.1
6	19.7	35.9	30.1	18	30.6	47.9	35.7
7	21.1	41.4	29.7	19	28.0	42.3	35.2
8	24.6	41.9	33.0	20	25.4	41.6	34.8
9	25.7	42.5	33.7	21	24.1	41.1	34.3
10	26.4	43.0	34.2	22	23.4	40.5	33.9
11	27.1	43.5	34.8	23	22.7	40.0	33.5
12	27.5	44.1	35.5	24	21.9	39.4	33.0

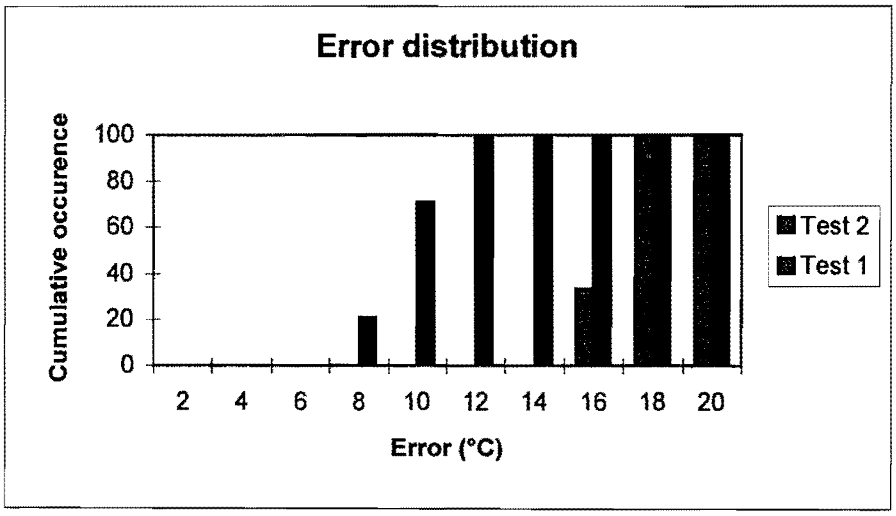




STUDY 70

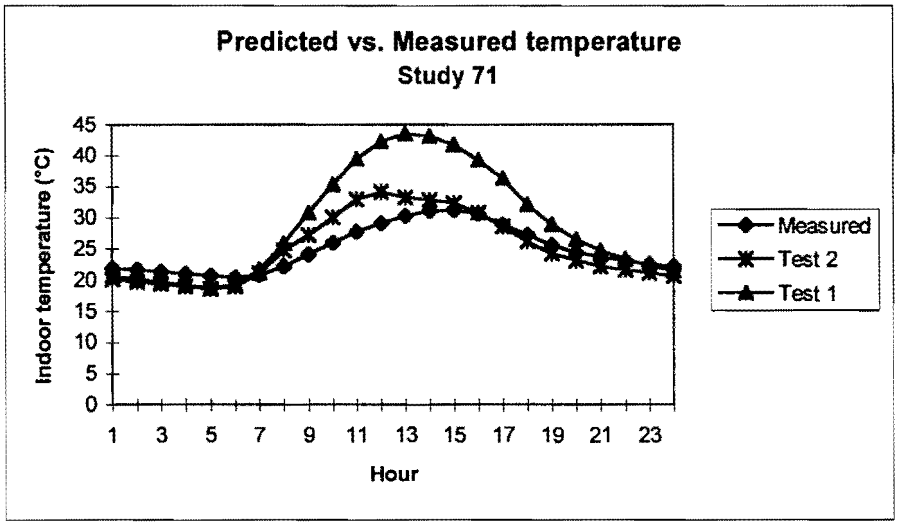
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	18.0	34.7	28.5	13	22.3	38.6	31.2
2	17.5	34.3	28.2	14	23.0	39.0	31.6
3	17.4	33.9	27.8	15	23.4	39.4	32.0
4	16.7	33.4	27.5	16	23.6	39.8	32.4
5	16.6	33.0	27.1	17	23.7	40.2	32.8
6	16.4	32.6	26.8	18	23.9	40.5	30.6
7	17.0	32.3	26.5	19	23.8	40.8	30.3
8	18.7	36.3	28.9	20	22.7	36.8	30.0
9	20.0	36.8	29.5	21	22.2	36.4	29.7
10	20.9	37.3	29.9	22	21.6	36.0	29.5
11	21.3	37.8	30.4	23	21.1	35.6	29.2
12	21.8	38.2	30.8	24	19.5	35.2	28.9

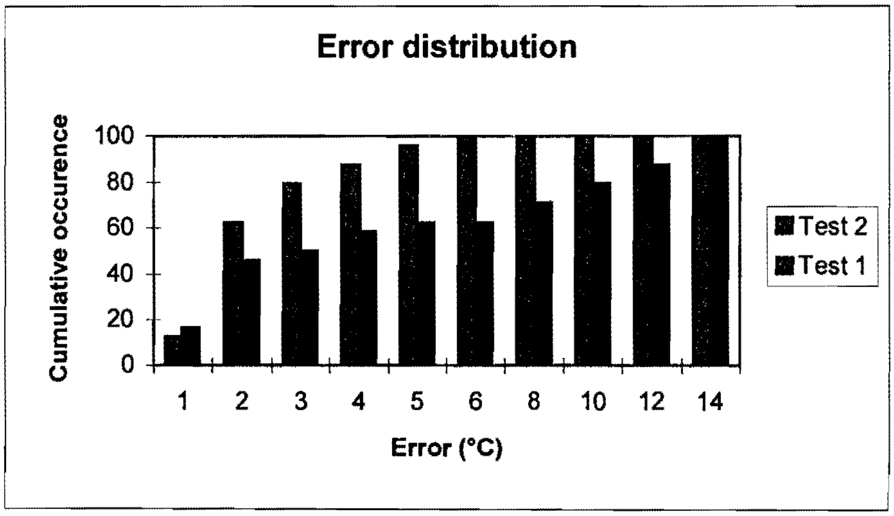




STUDY 71

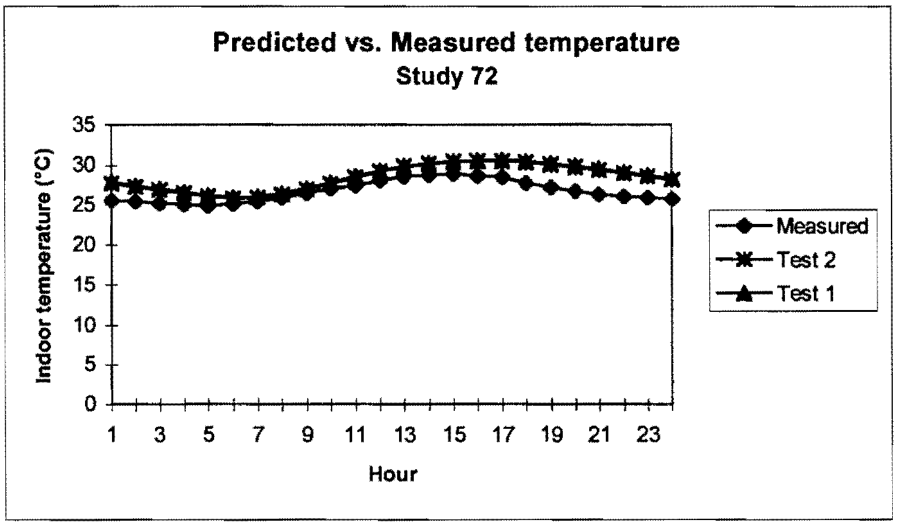
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.9	20.1	20.8	13	30.2	33.2	43.5
2	21.7	19.7	20.2	14	31.0	32.8	43.1
3	21.4	19.3	19.7	15	31.1	32.3	41.7
4	21.0	18.9	19.2	16	30.5	30.7	39.3
5	20.7	18.5	18.8	17	28.9	28.5	36.2
6	20.4	19.0	19.3	18	27.2	26.1	32.1
7	20.8	21.2	21.7	19	25.5	24.2	28.9
8	22.2	24.7	25.8	20	24.4	23.1	26.5
9	24.1	27.2	30.8	21	23.6	22.2	24.7
10	25.9	30.0	35.4	22	23.0	21.6	23.3
11	27.7	32.9	39.5	23	22.5	21.1	22.3
12	29.1	34.0	42.3	24	22.2	20.6	21.5

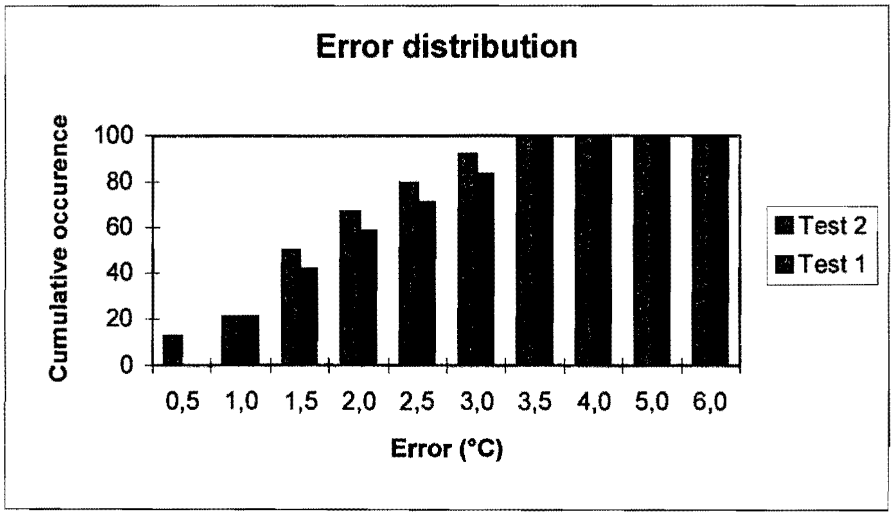




STUDY 72

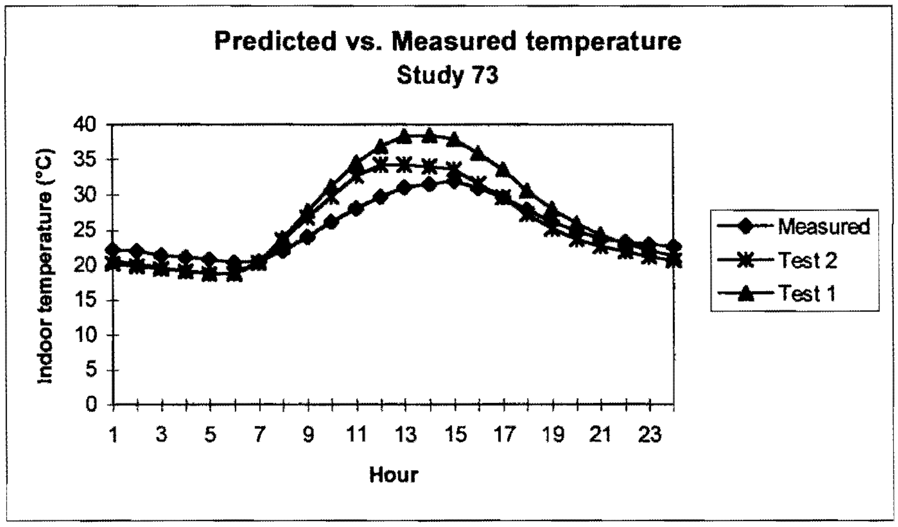
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.6	27.7	27.9	13	28.6	29.8	29.9
2	25.4	27.3	27.5	14	28.8	30.1	30.2
3	25.2	26.9	27.1	15	28.9	30.4	30.5
4	25.0	26.5	26.7	16	28.7	30.5	30.6
5	24.9	26.1	26.3	17	28.5	30.5	30.6
6	25.1	25.8	26.0	18	27.8	30.3	30.4
7	25.4	25.9	26.1	19	27.2	30.0	30.2
8	25.9	26.3	26.5	20	26.7	29.7	29.9
9	26.5	27.0	27.1	21	26.3	29.4	29.6
10	27.1	27.7	27.9	22	26.1	29.0	29.2
11	27.5	28.6	28.7	23	25.9	28.6	28.8
12	28.1	29.3	29.4	24	25.8	28.2	28.4

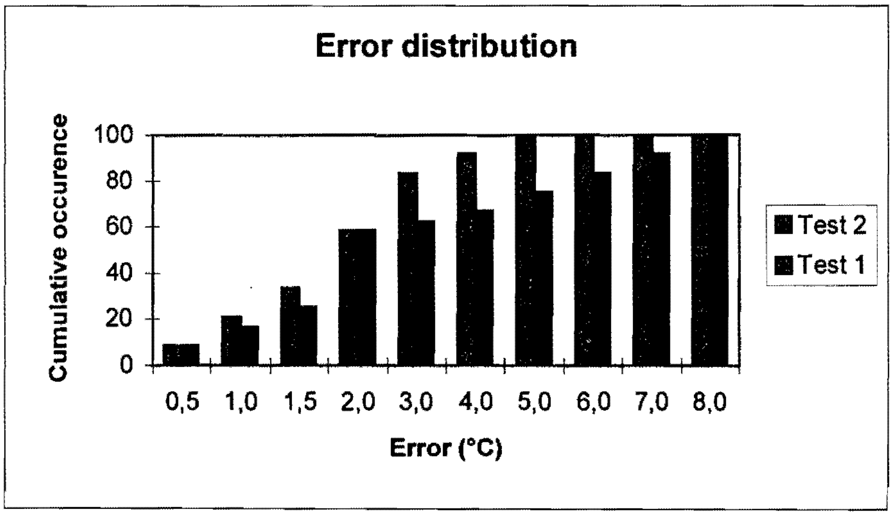




STUDY 73

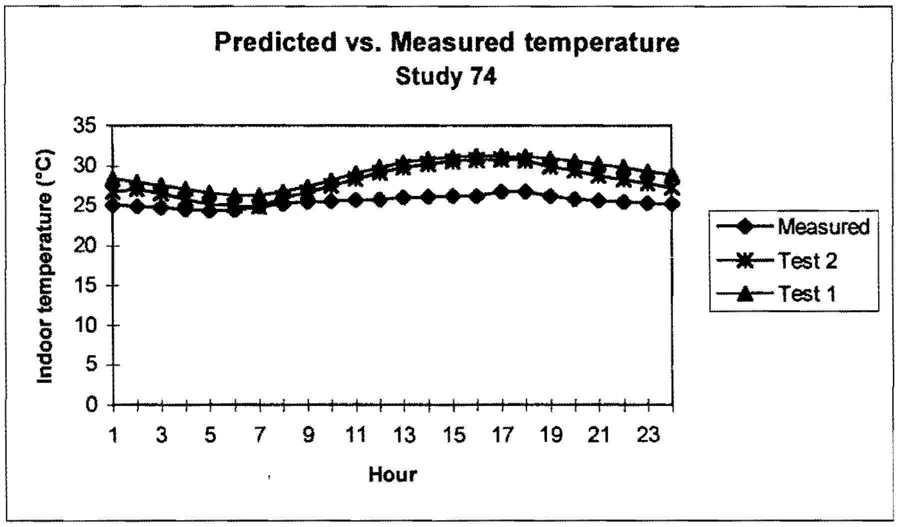
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.2	20.2	20.7	13	31.0	34.2	38.3
2	22.0	19.9	20.1	14	31.5	34.0	38.4
3	21.4	19.5	19.7	15	31.9	33.7	37.9
4	21.1	19.1	19.2	16	30.9	31.6	35.9
5	20.8	18.7	18.8	17	29.6	29.6	33.7
6	20.4	18.7	18.9	18	27.9	27.2	30.6
7	20.6	20.3	20.5	19	26.1	25.2	28.0
8	22.0	23.6	23.9	20	24.9	23.7	25.9
9	24.1	26.7	27.7	21	23.8	22.7	24.3
10	26.1	29.7	31.2	22	23.3	21.9	23.1
11	28.1	32.7	34.5	23	23.0	21.2	22.1
12	29.7	34.3	36.9	24	22.7	20.6	21.3

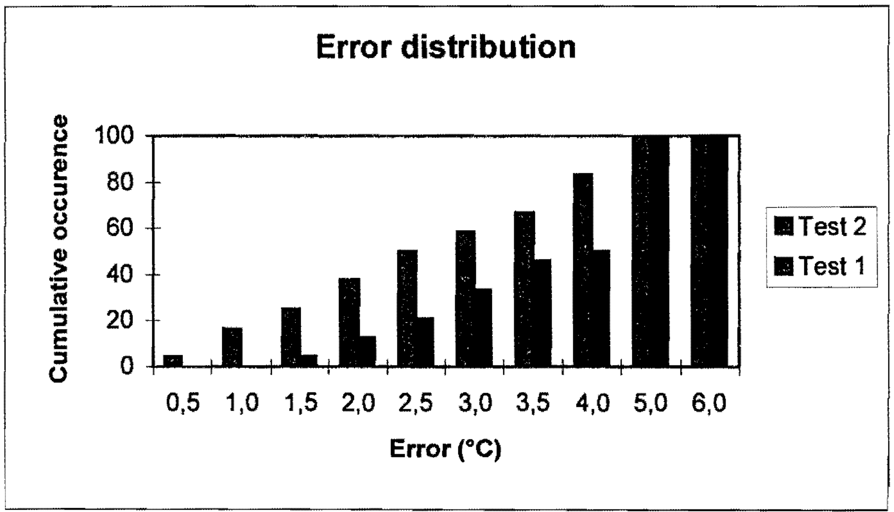




STUDY 74

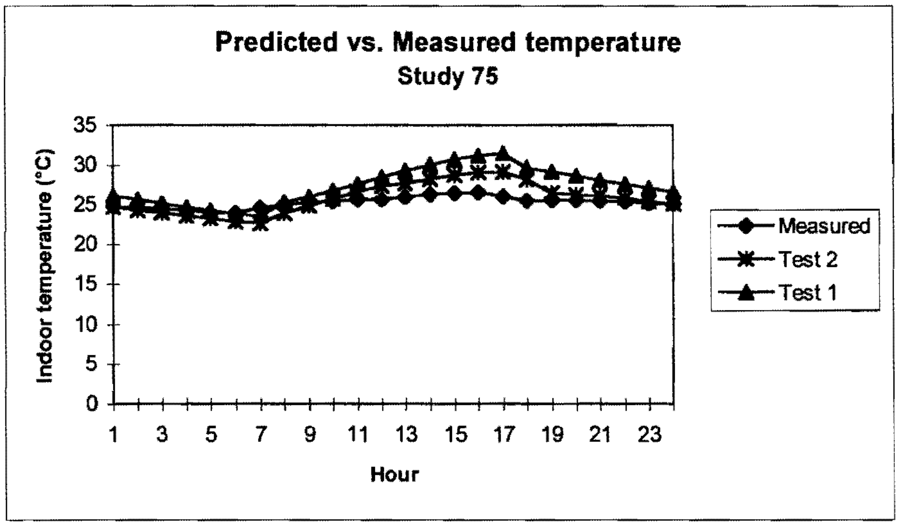
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.0	26.8	28.4	13	26.0	29.8	30.4
2	24.9	27.1	28.0	14	26.1	30.2	30.8
3	24.7	26.5	27.5	15	26.2	30.5	31.1
4	24.5	25.8	27.1	16	26.2	30.7	31.2
5	24.3	25.1	26.6	17	26.7	30.8	31.2
6	24.4	25.0	26.3	18	26.7	30.7	31.1
7	24.8	24.8	26.3	19	26.2	29.9	30.9
8	25.2	25.9	26.7	20	25.8	29.4	30.6
9	25.4	26.7	27.4	21	25.6	28.8	30.2
10	25.5	27.5	28.2	22	25.4	28.3	29.8
11	25.7	28.4	29.1	23	25.3	27.8	29.3
12	25.8	29.2	29.8	24	25.2	27.3	28.9

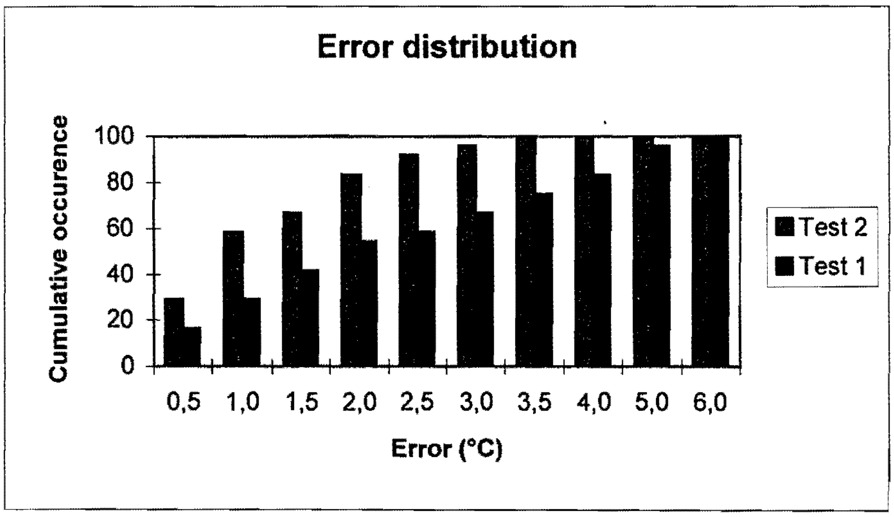




STUDY 75

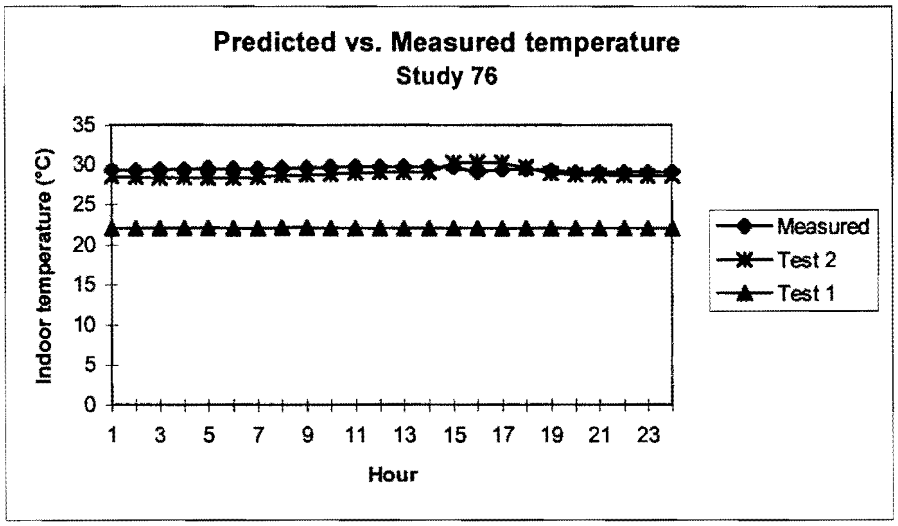
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	24.8	24.7	26.2	13	26.0	27.7	29.4
2	24.7	24.3	25.7	14	26.3	28.3	30.1
3	24.5	24.0	25.2	15	26.5	28.8	30.7
4	24.4	23.6	24.8	16	26.6	29.1	31.1
5	24.0	23.3	24.3	17	26.1	29.2	31.4
6	24.0	22.8	23.9	18	25.5	28.2	29.7
7	24.6	22.7	23.6	19	25.6	26.5	29.1
8	25.0	23.9	25.4	20	25.6	26.2	28.7
9	25.3	24.9	26.0	21	25.5	26.2	28.1
10	25.4	25.8	26.8	22	25.4	25.8	27.6
11	25.7	26.6	27.6	23	25.2	25.4	27.1
12	25.7	27.4	28.5	24	25.1	25.1	26.6

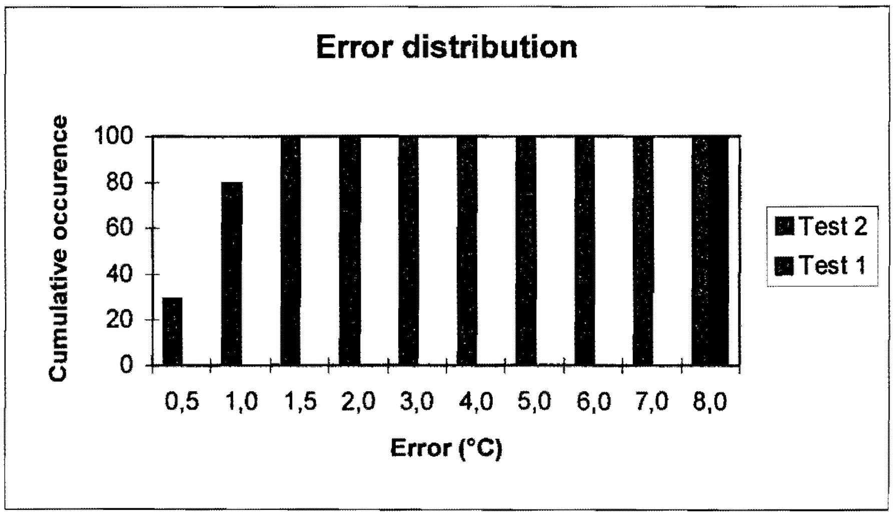




STUDY 76

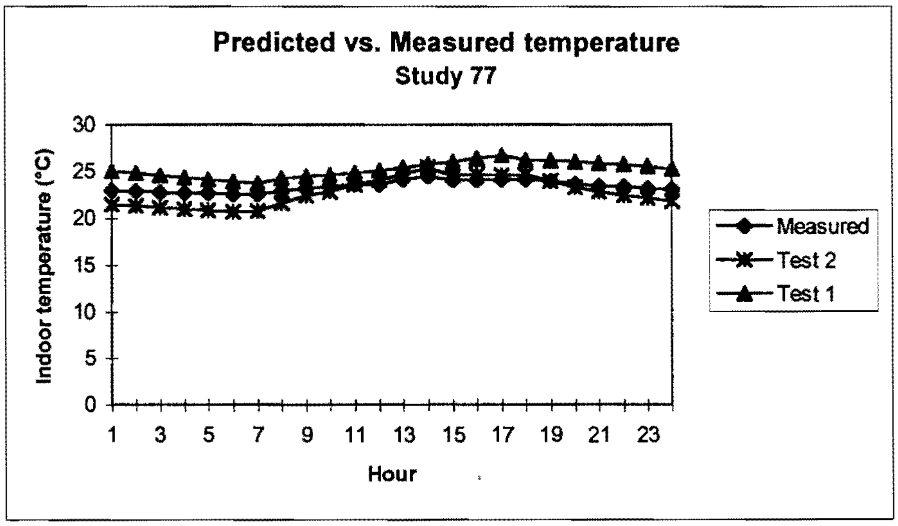
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	29.3	28.5	22.1	13	29.7	29.1	22.1
2	29.3	28.4	22.1	14	29.7	29.1	22.1
3	29.4	28.4	22.1	15	29.7	30.2	22.1
4	29.4	28.4	22.1	16	29.1	30.3	22.1
5	29.6	28.4	22.1	17	29.4	30.3	22.1
6	29.5	28.3	22.1	18	29.5	29.6	22.0
7	29.5	28.4	22.1	19	29.3	28.9	22.0
8	29.6	28.7	22.1	20	29.1	28.8	22.1
9	29.6	28.8	22.1	21	29.1	28.7	22.1
10	29.7	28.9	22.1	22	29.1	28.7	22.1
11	29.7	29.0	22.1	23	29.1	28.6	22.1
12	29.7	29.1	22.1	24	29.2	28.6	22.1

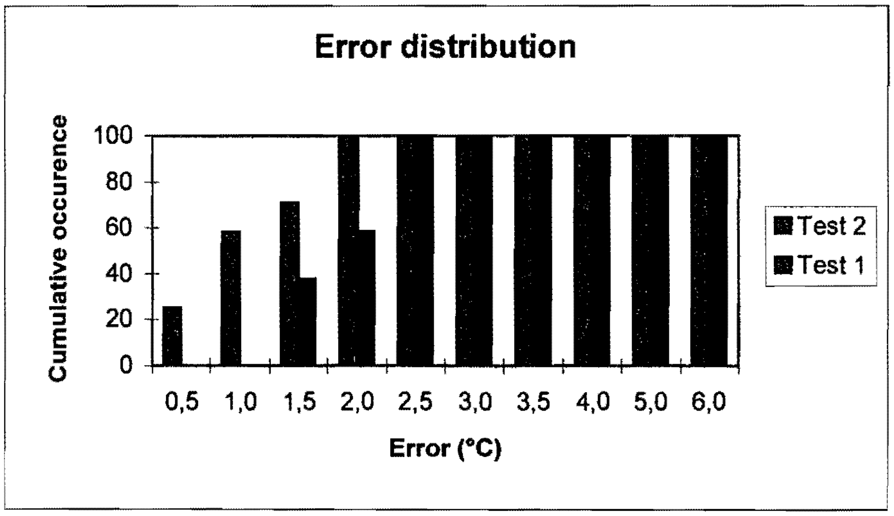




STUDY 77

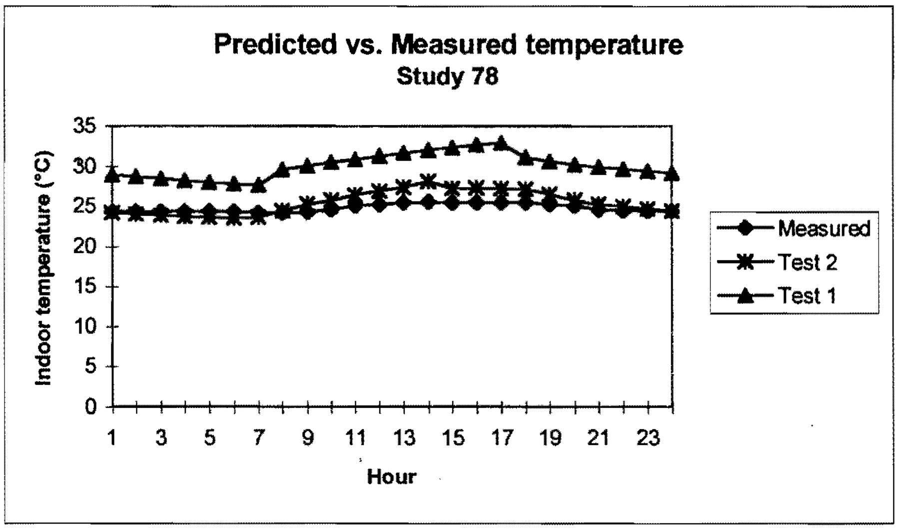
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.0	21.5	25.1	13	24.2	24.7	25.4
2	22.9	21.3	24.8	14	24.5	25.4	25.8
3	22.8	21.1	24.6	15	24.1	24.6	26.1
4	22.7	21.0	24.4	16	24.1	24.7	26.4
5	22.7	20.8	24.2	17	24.2	24.6	26.7
6	22.6	20.7	23.9	18	24.2	24.7	26.3
7	22.6	20.8	23.8	19	24.0	24.0	26.2
8	22.9	21.6	24.3	20	23.7	23.3	26.1
9	23.2	22.4	24.5	21	23.5	22.8	25.9
10	23.4	22.9	24.7	22	23.4	22.5	25.7
11	23.6	23.6	24.9	23	23.2	22.2	25.5
12	23.6	24.1	25.2	24	23.1	21.8	25.3

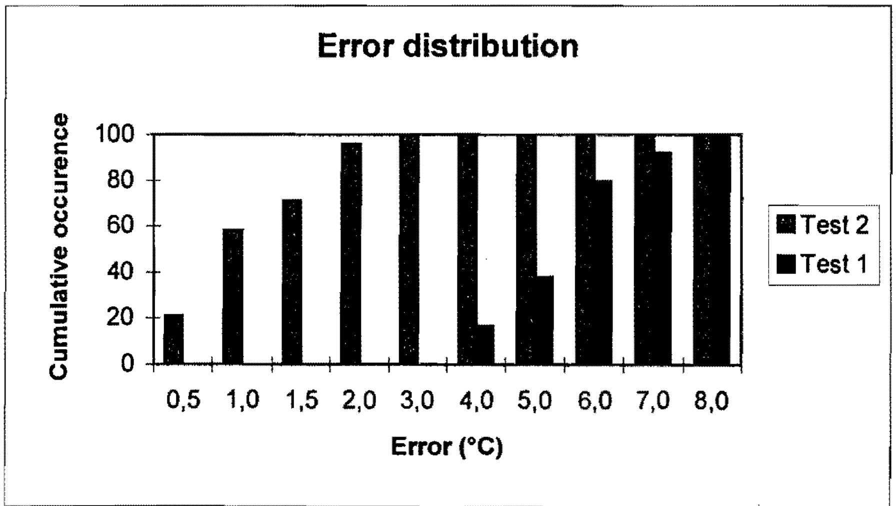




STUDY 78

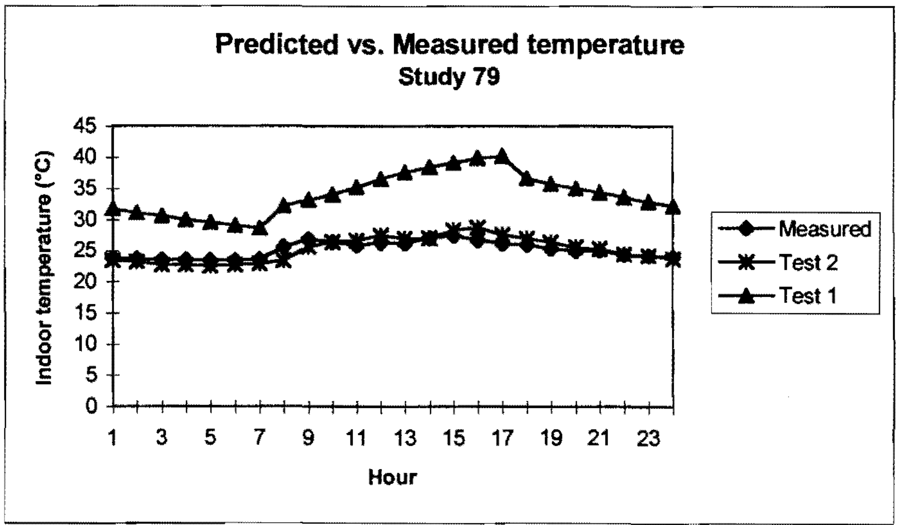
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	24.4	24.2	28.9	13	25.5	27.4	31.7
2	24.4	24.1	28.7	14	25.6	28.1	32.0
3	24.4	23.9	28.4	15	25.5	27.2	32.3
4	24.4	23.8	28.2	16	25.5	27.3	32.7
5	24.4	23.7	28.0	17	25.5	27.2	32.9
6	24.4	23.6	27.8	18	25.5	27.2	31.1
7	24.2	23.7	27.6	19	25.3	26.5	30.6
8	24.2	24.4	29.6	20	25.1	25.8	30.3
9	24.3	25.3	30.1	21	24.6	25.3	29.9
10	24.6	25.7	30.5	22	24.5	25.0	29.7
11	25.1	26.4	30.9	23	24.5	24.7	29.4
12	25.3	26.9	31.3	24	24.5	24.5	29.2

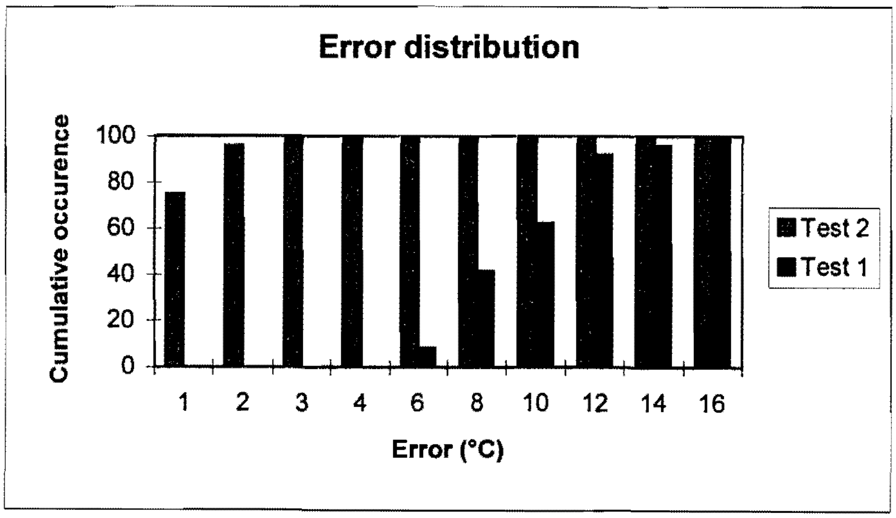




STUDY 79

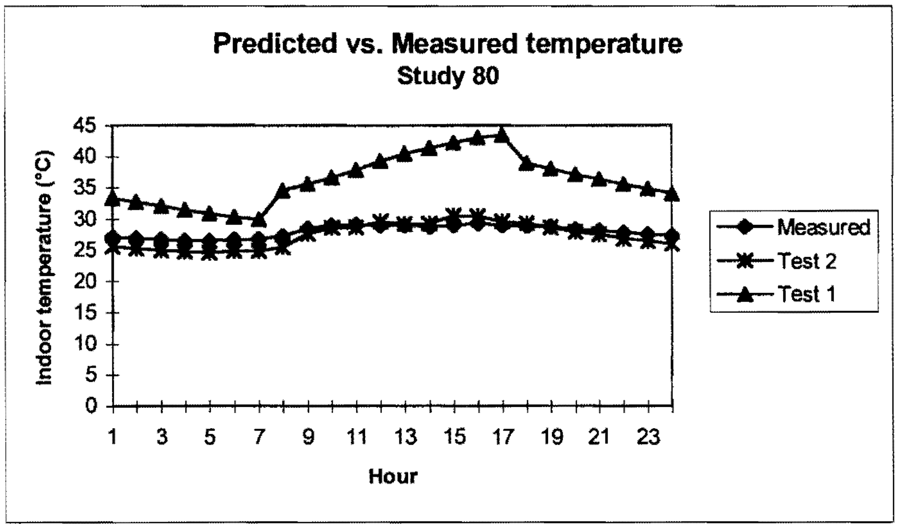
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.9	23.4	31.7	13	26.2	27.0	37.6
2	23.8	23.2	31.1	14	27.1	27.1	38.5
3	23.5	22.7	30.6	15	27.4	28.4	39.2
4	23.5	22.7	30.1	16	26.8	28.7	39.9
5	23.4	22.5	29.6	17	26.2	27.6	40.2
6	23.4	22.7	29.1	18	26.0	27.0	36.6
7	23.6	22.9	28.7	19	25.4	26.4	35.8
8	25.6	23.5	32.3	20	25.0	25.6	35.1
9	26.9	25.7	33.3	21	25.1	25.3	34.4
10	26.5	26.5	34.1	22	24.4	24.4	33.6
11	25.9	26.6	35.2	23	24.3	24.2	33.0
12	26.4	27.5	36.6	24	24.1	23.8	32.3

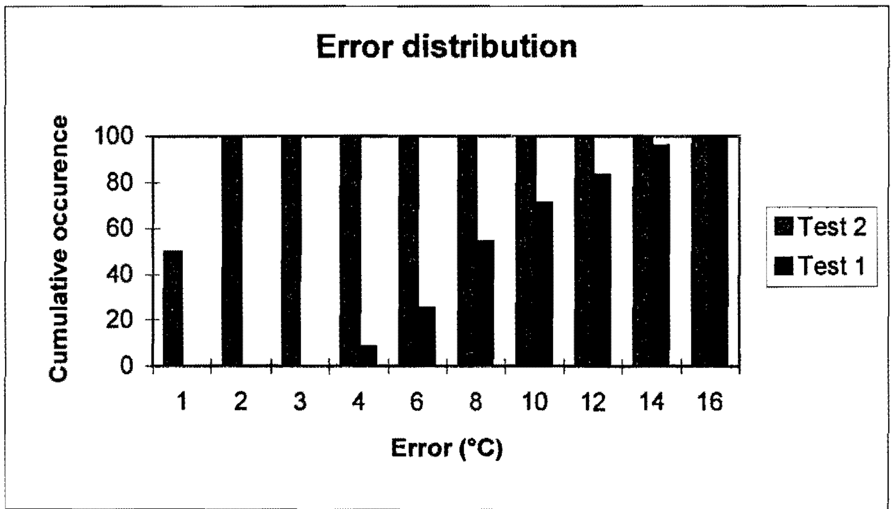




STUDY 80

Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	27.1	25.7	33.3	13	29.0	29.1	40.4
2	26.9	25.3	32.7	14	28.7	29.3	41.4
3	26.7	25.0	32.0	15	29.0	30.6	42.2
4	26.5	24.8	31.4	16	29.3	30.4	43.0
5	26.5	24.6	30.9	17	29.0	29.6	43.4
6	26.7	24.9	30.4	18	28.9	29.3	39.0
7	26.8	24.9	29.9	19	28.7	28.6	38.0
8	27.2	25.6	34.4	20	28.3	27.9	37.1
9	28.4	27.6	35.6	21	28.1	27.5	36.3
10	29.0	28.5	36.6	22	27.8	26.9	35.5
11	29.1	28.7	37.8	23	27.5	26.4	34.7
12	29.0	29.6	39.3	24	27.3	26.1	34.0





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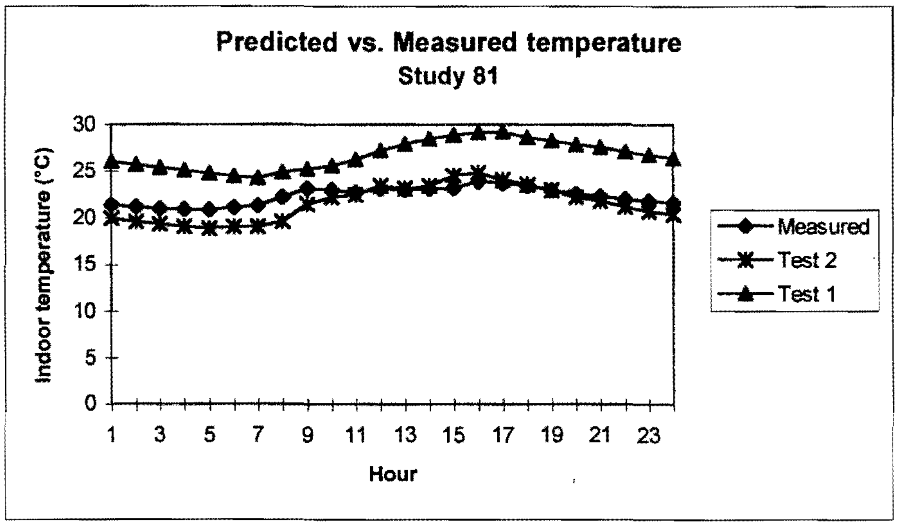
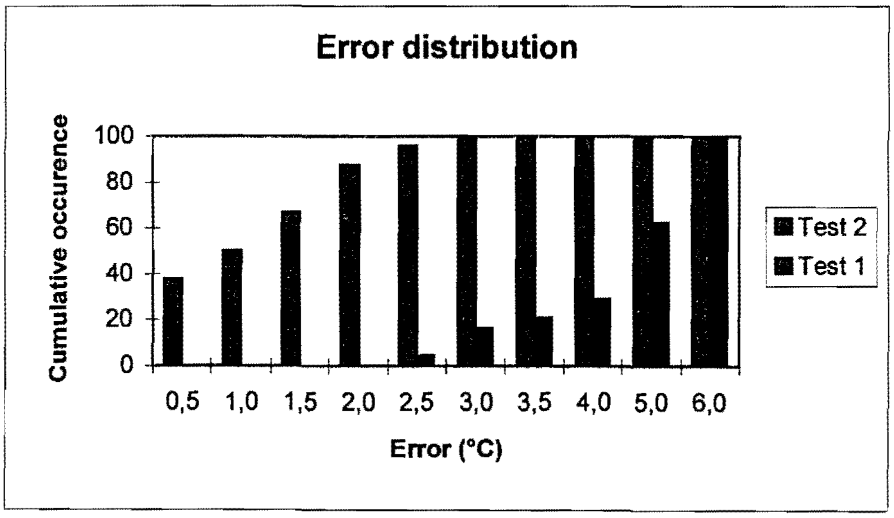
STUDY 81

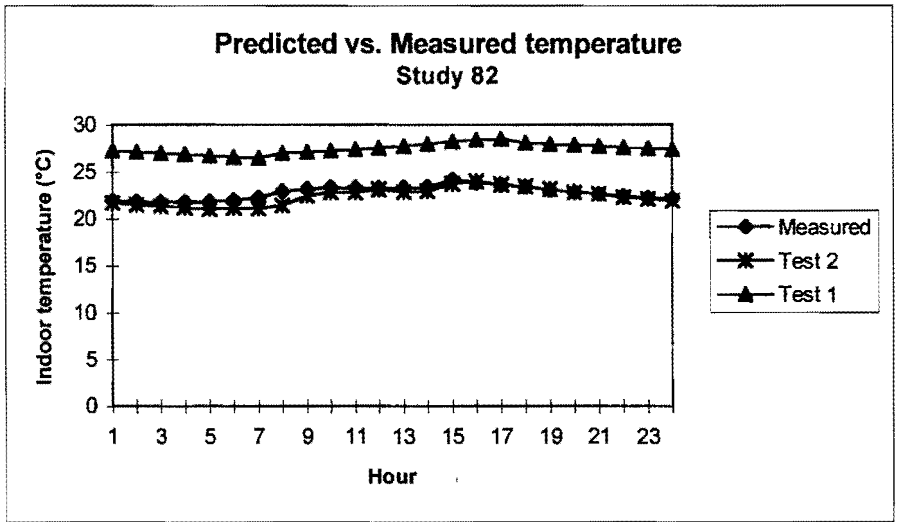
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.4	19.9	26.0	13	23.0	23.2	27.9
2	21.2	19.6	25.7	14	23.1	23.4	28.5
3	21.0	19.3	25.4	15	23.2	24.5	28.9
4	20.9	19.0	25.0	16	23.9	24.8	29.2
5	20.8	18.8	24.8	17	23.7	24.1	29.3
6	21.1	19.0	24.5	18	23.4	23.5	28.6
7	21.3	19.0	24.3	19	22.9	22.9	28.2
8	22.2	19.6	24.9	20	22.6	22.2	27.9
9	23.1	21.5	25.2	21	22.3	21.8	27.5
10	23.0	22.2	25.6	22	22.0	21.2	27.1
11	22.7	22.5	26.3	23	21.8	20.7	26.7
12	23.1	23.4	27.3	24	21.6	20.4	26.4

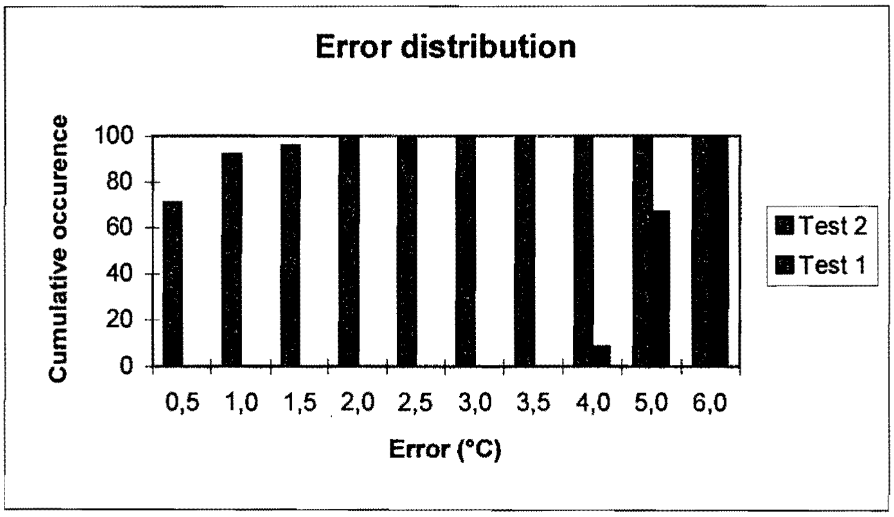




STUDY 82

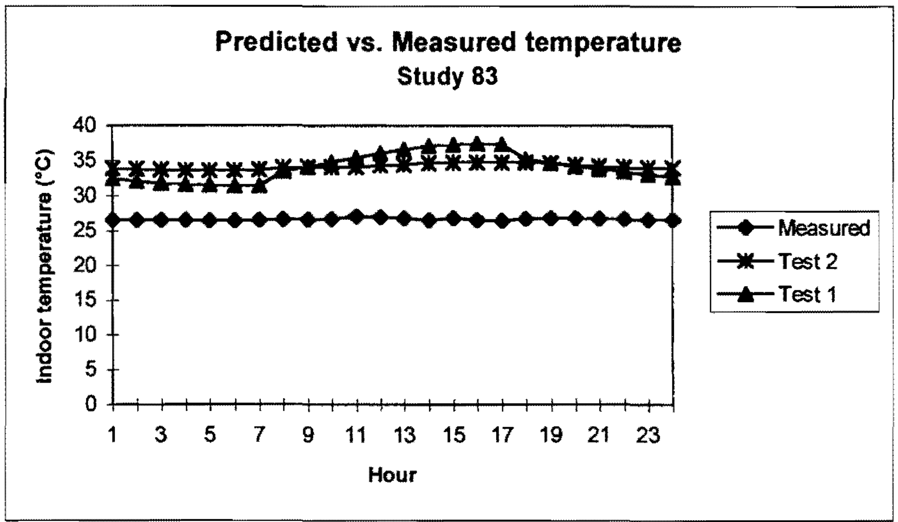
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.0	21.7	27.3	13	23.3	22.9	27.8
2	21.9	21.6	27.2	14	23.4	23.0	28.0
3	21.8	21.4	27.0	15	24.2	23.8	28.2
4	21.8	21.2	26.9	16	23.9	24.0	28.4
5	21.9	21.1	26.8	17	23.7	23.7	28.6
6	22.0	21.2	26.6	18	23.5	23.4	28.1
7	22.3	21.1	26.5	19	23.1	23.2	28.0
8	23.0	21.4	27.0	20	22.9	22.9	27.9
9	23.2	22.5	27.2	21	22.7	22.7	27.8
10	23.4	22.9	27.3	22	22.5	22.4	27.7
11	23.3	22.9	27.4	23	22.3	22.2	27.6
12	23.3	23.2	27.6	24	22.2	22.0	27.4

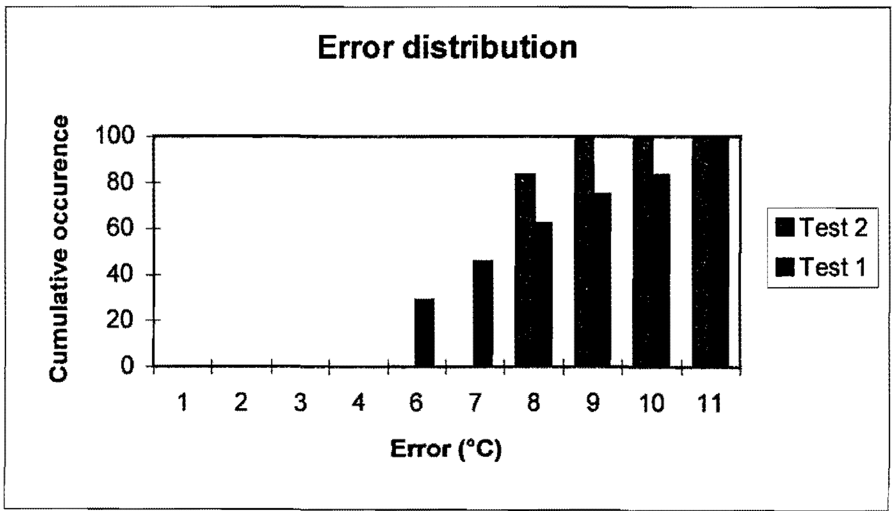




STUDY 83

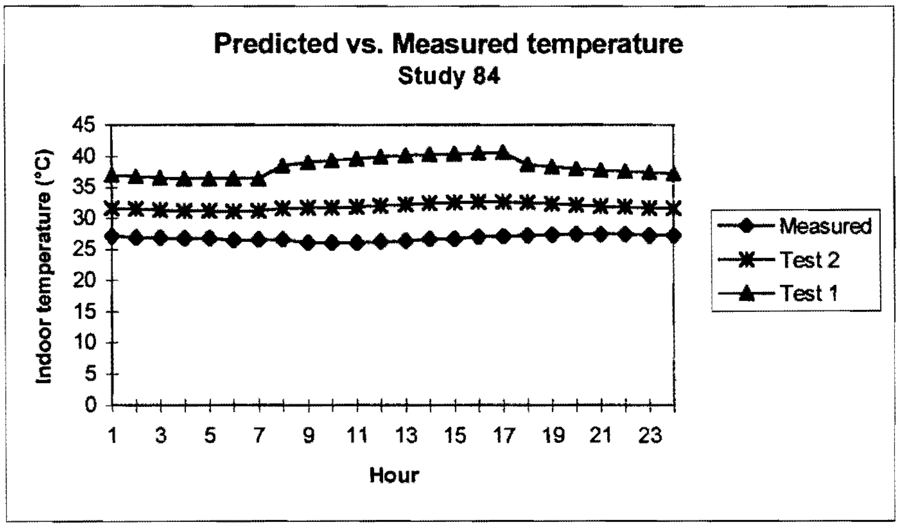
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	26.5	33.9	32.4	13	26.8	34.4	36.6
2	26.5	33.8	32.1	14	26.5	34.7	37.0
3	26.5	33.7	31.7	15	26.8	34.7	37.3
4	26.5	33.7	31.6	16	26.5	34.8	37.4
5	26.4	33.6	31.5	17	26.4	34.8	37.4
6	26.4	33.6	31.4	18	26.7	34.7	35.2
7	26.5	33.7	31.4	19	26.8	34.6	34.7
8	26.6	34.0	33.5	20	26.8	34.3	34.1
9	26.6	34.1	34.1	21	26.7	34.2	33.8
10	26.7	34.1	34.7	22	26.7	34.1	33.4
11	27.0	34.1	35.4	23	26.6	34.0	33.0
12	26.9	34.4	36.0	24	26.6	34.0	32.7

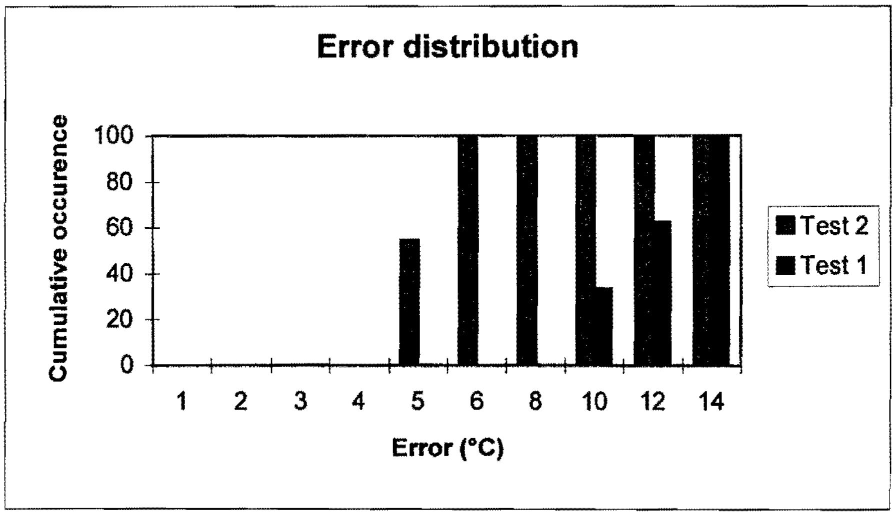




STUDY 84

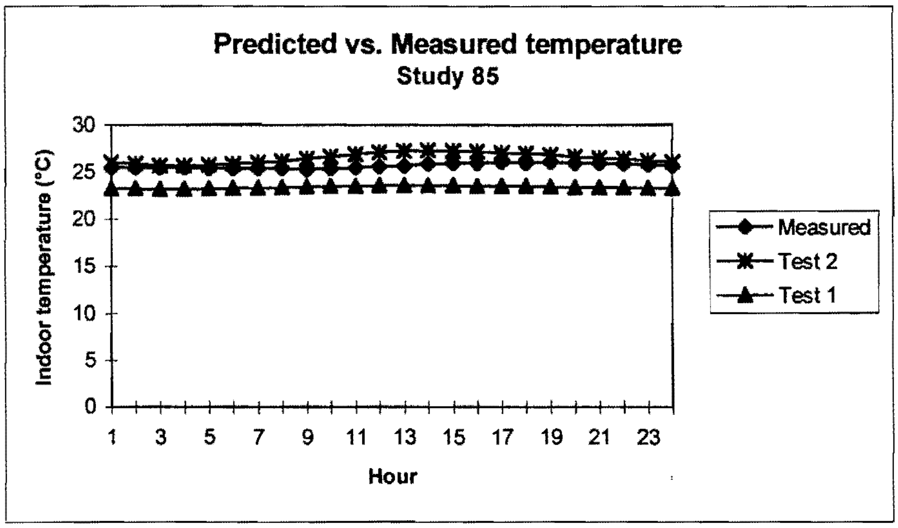
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	27.1	31.6	36.9	13	26.4	32.2	40.2
2	26.9	31.4	36.7	14	26.7	32.4	40.3
3	26.9	31.3	36.5	15	26.7	32.5	40.5
4	26.8	31.2	36.4	16	27.0	32.6	40.6
5	26.8	31.1	36.4	17	27.1	32.6	40.7
6	26.5	31.1	36.3	18	27.2	32.5	38.6
7	26.6	31.2	36.3	19	27.3	32.3	38.3
8	26.6	31.5	38.5	20	27.4	32.1	37.9
9	26.0	31.6	39.0	21	27.4	31.8	37.7
10	26.0	31.7	39.3	22	27.4	31.7	37.5
11	26.0	31.7	39.6	23	27.2	31.6	37.3
12	26.2	32.0	39.9	24	27.2	31.6	37.1

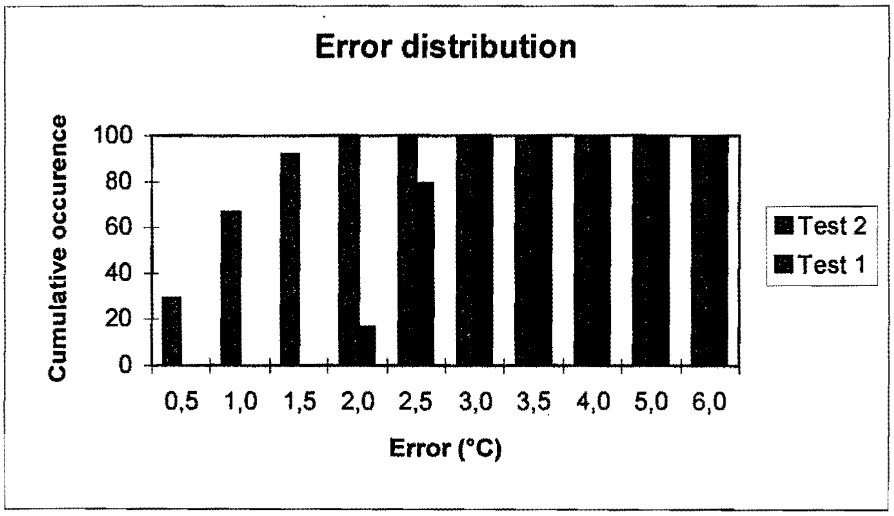




STUDY 85

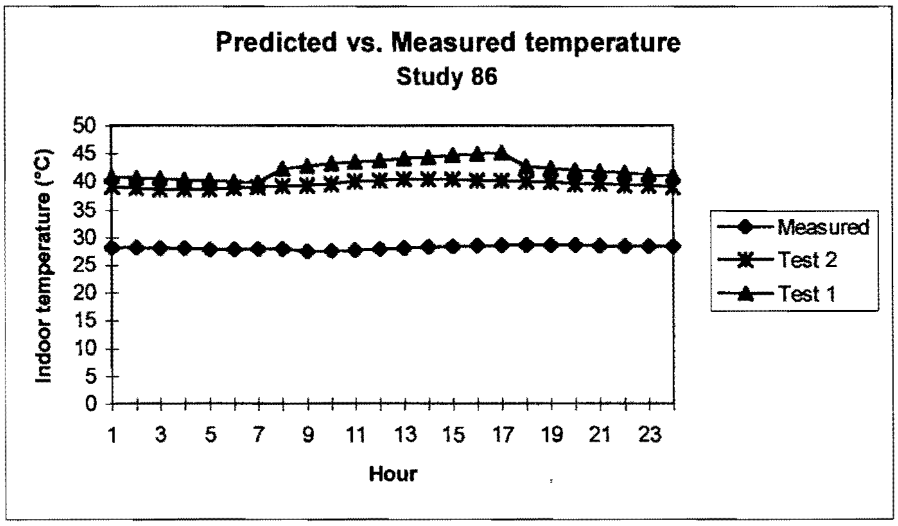
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.5	26.0	23.3	13	25.7	27.3	23.6
2	25.5	25.9	23.3	14	25.9	27.4	23.6
3	25.5	25.7	23.2	15	26.0	27.3	23.6
4	25.5	25.7	23.2	16	26.0	27.2	23.6
5	25.4	25.8	23.3	17	26.1	27.1	23.5
6	25.4	25.9	23.3	18	26.0	27.0	23.5
7	25.4	26.0	23.4	19	26.1	26.9	23.5
8	25.4	26.2	23.4	20	26.0	26.7	23.4
9	25.3	26.4	23.5	21	26.0	26.6	23.4
10	25.4	26.7	23.5	22	25.9	26.5	23.4
11	25.5	26.9	23.6	23	25.8	26.3	23.4
12	25.6	27.2	23.6	24	25.7	26.1	23.3

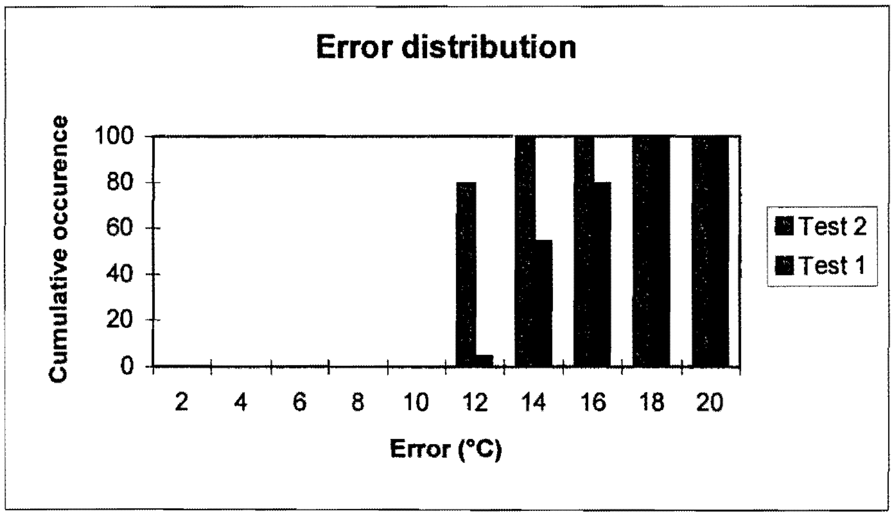




STUDY 86

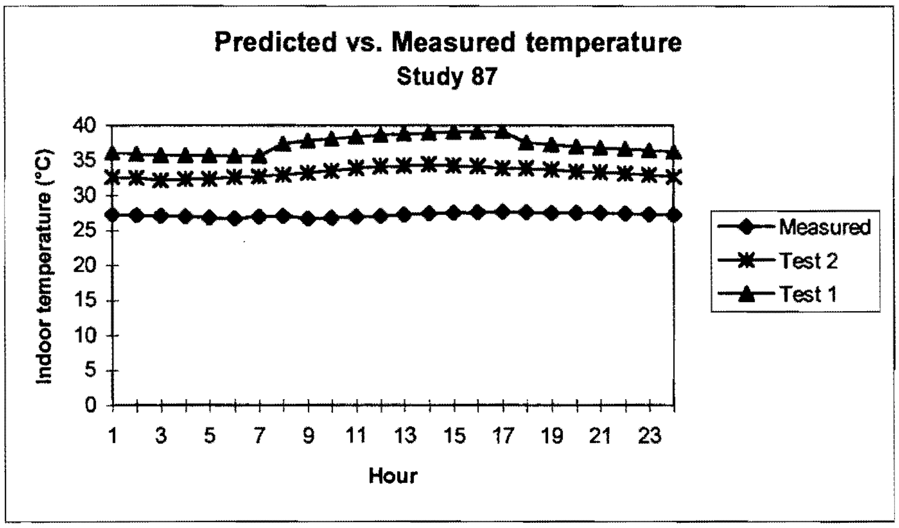
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	28.1	39.1	40.9	13	28.0	40.4	44.1
2	28.1	38.9	40.7	14	28.2	40.3	44.4
3	28.0	38.7	40.5	15	28.4	40.4	44.6
4	28.0	38.7	40.3	16	28.5	40.2	44.9
5	27.8	38.7	40.1	17	28.6	40.1	45.1
6	27.8	38.9	39.9	18	28.6	40.1	42.7
7	27.9	39.0	39.8	19	28.6	40.0	42.3
8	27.9	39.2	42.3	20	28.6	39.6	42.0
9	27.4	39.3	42.8	21	28.5	39.7	41.8
10	27.5	39.6	43.2	22	28.4	39.4	41.5
11	27.7	40.0	43.5	23	28.4	39.3	41.2
12	27.9	40.1	43.8	24	28.3	39.1	41.1

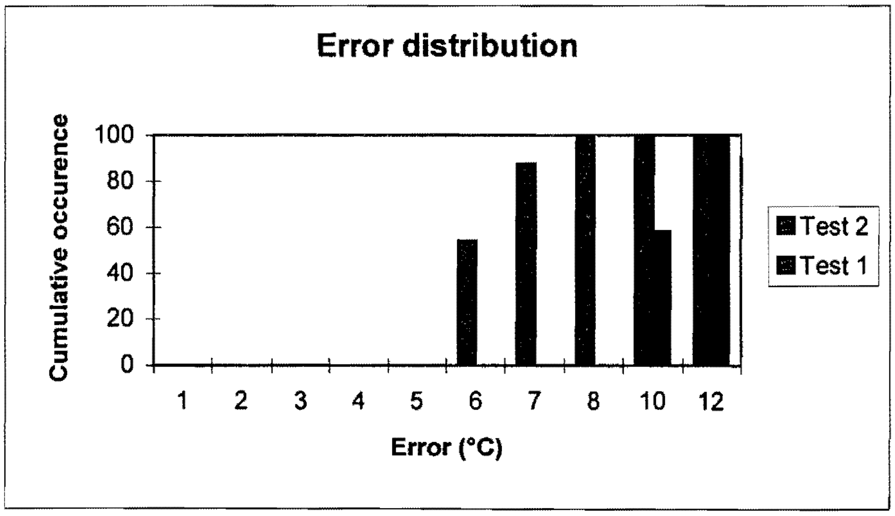




STUDY 87

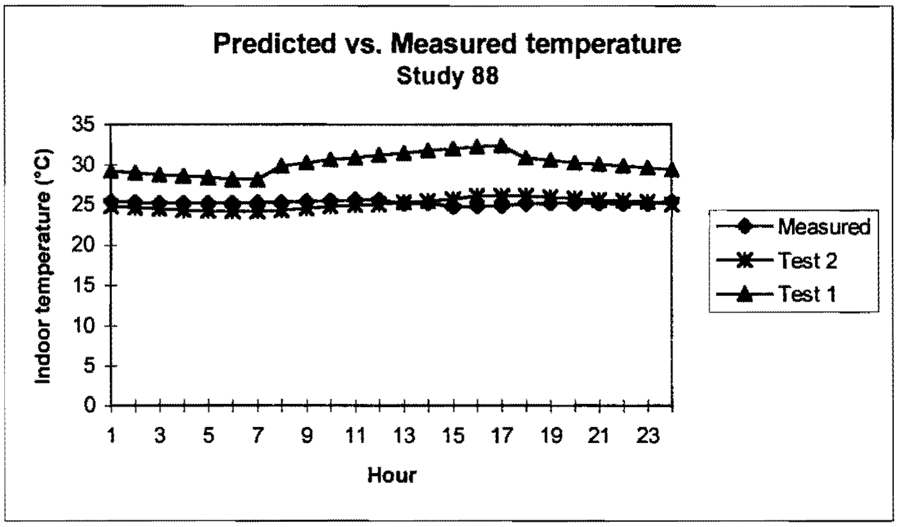
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	27.2	32.6	36.0	13	27.2	34.2	38.8
2	27.1	32.5	35.9	14	27.4	34.5	38.9
3	27.0	32.2	35.7	15	27.5	34.3	39.0
4	26.9	32.3	35.6	16	27.6	34.2	39.1
5	26.8	32.3	35.6	17	27.7	33.9	39.2
6	26.7	32.6	35.6	18	27.6	33.9	37.5
7	26.9	32.7	35.6	19	27.5	33.7	37.2
8	27.0	33.0	37.3	20	27.5	33.4	36.9
9	26.7	33.2	37.7	21	27.5	33.3	36.7
10	26.8	33.5	38.1	22	27.4	33.2	36.6
11	26.9	33.9	38.3	23	27.3	32.9	36.4
12	27.0	34.2	38.6	24	27.2	32.7	36.2

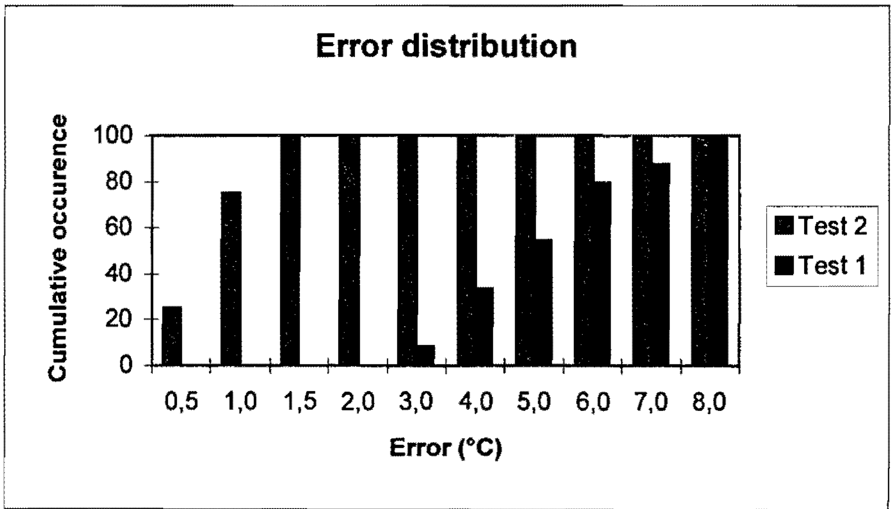




STUDY 88

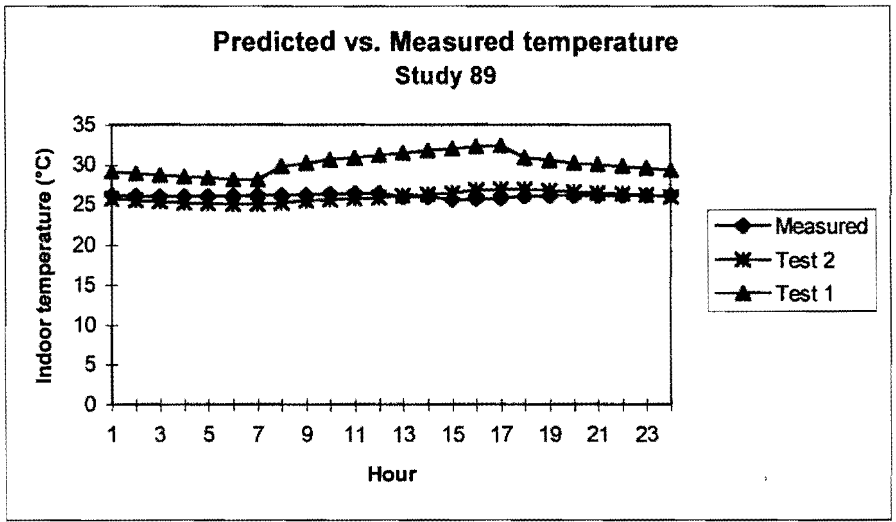
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.4	24.8	29.1	13	25.1	25.3	31.4
2	25.3	24.7	28.9	14	25.2	25.4	31.7
3	25.2	24.5	28.7	15	24.7	25.7	32.0
4	25.2	24.3	28.5	16	24.8	26.1	32.3
5	25.2	24.2	28.3	17	24.9	26.1	32.4
6	25.2	24.1	28.1	18	25.1	26.1	30.9
7	25.3	24.2	28.1	19	25.2	26.0	30.5
8	25.3	24.3	29.8	20	25.2	25.8	30.3
9	25.4	24.6	30.3	21	25.2	25.6	30.1
10	25.5	24.8	30.6	22	25.1	25.5	29.8
11	25.6	25.0	30.9	23	25.1	25.3	29.6
12	25.6	25.0	31.2	24	25.4	25.1	29.4

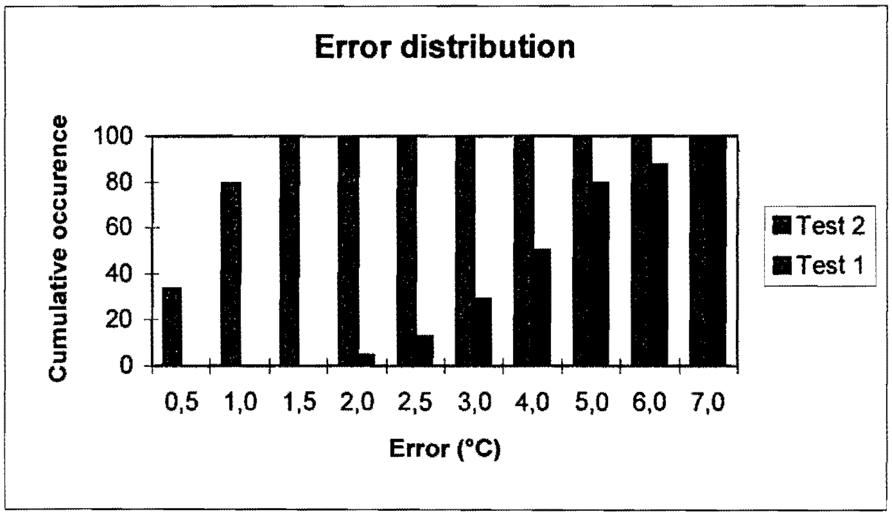




STUDY 89

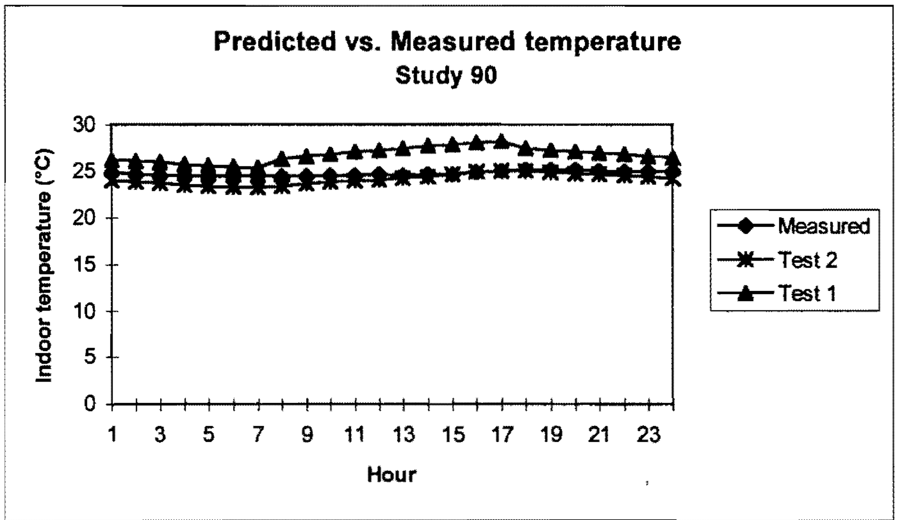
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	26.2	25.7	29.1	13	25.9	26.1	31.4
2	26.1	25.6	28.9	14	25.9	26.2	31.7
3	26.0	25.4	28.7	15	25.6	26.4	32.0
4	26.0	25.2	28.5	16	25.7	26.8	32.3
5	26.0	25.1	28.3	17	25.8	26.9	32.4
6	26.1	25.0	28.1	18	26.0	26.9	30.9
7	26.2	25.1	28.1	19	26.1	26.7	30.5
8	26.2	25.2	29.8	20	26.1	26.6	30.3
9	26.2	25.4	30.3	21	26.1	26.4	30.1
10	26.3	25.6	30.6	22	26.1	26.4	29.8
11	26.4	25.8	30.9	23	26.1	26.2	29.6
12	26.4	25.8	31.2	24	26.2	25.9	29.4

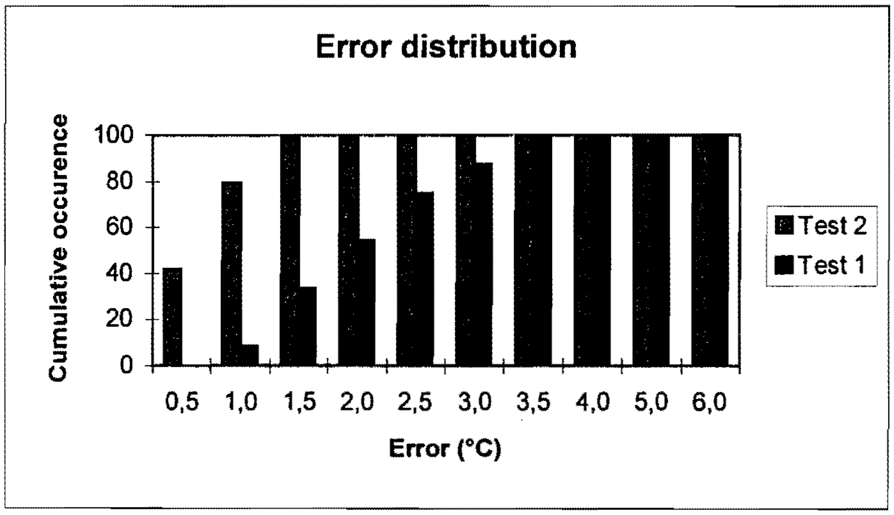




STUDY 90

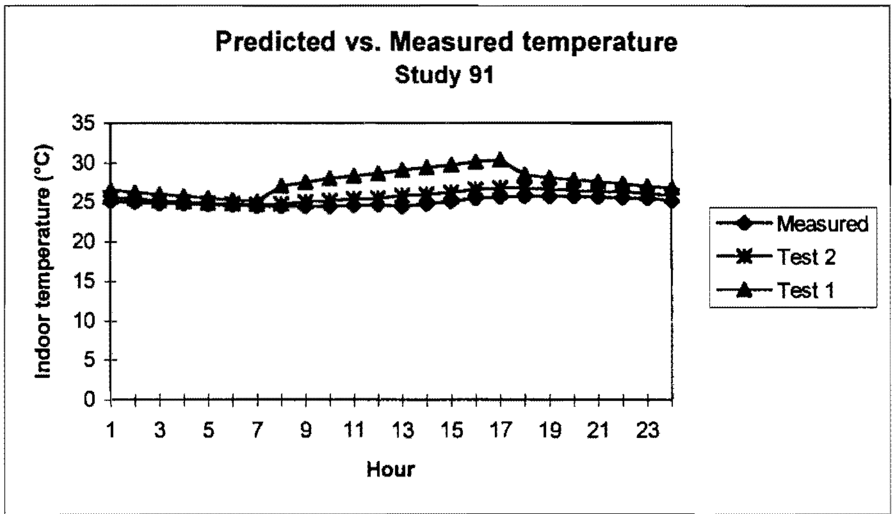
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	24.9	24.0	26.3	13	24.6	24.3	27.5
2	24.7	23.9	26.1	14	24.7	24.5	27.7
3	24.6	23.7	26.0	15	24.7	24.7	27.9
4	24.6	23.5	25.8	16	24.9	25.0	28.1
5	24.5	23.4	25.6	17	25.1	25.1	28.2
6	24.5	23.4	25.5	18	25.2	25.1	27.4
7	24.5	23.3	25.4	19	25.2	24.9	27.2
8	24.5	23.4	26.3	20	25.2	24.8	27.1
9	24.5	23.7	26.6	21	25.1	24.7	26.9
10	24.6	23.9	26.8	22	25.0	24.6	26.8
11	24.6	24.0	27.1	23	25.0	24.5	26.6
12	24.7	24.1	27.3	24	25.0	24.2	26.4

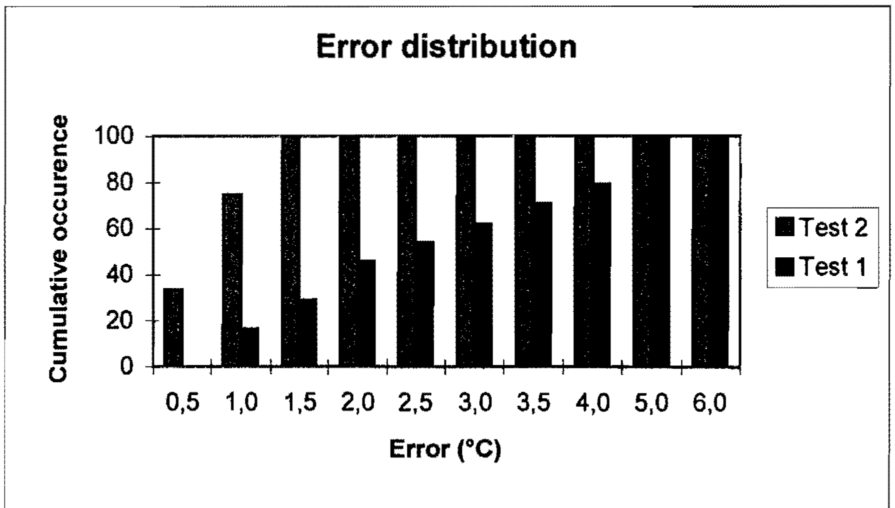




STUDY 91

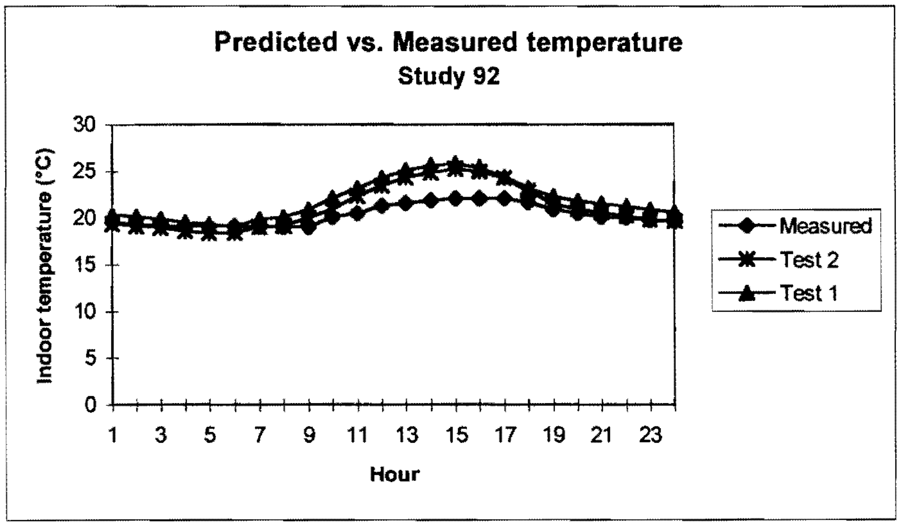
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	25.1	25.6	26.6	13	24.5	25.8	29.1
2	25	25.4	26.3	14	24.8	26.0	29.4
3	24.8	25.2	26.0	15	25.1	26.3	29.8
4	24.8	25.0	25.8	16	25.5	26.7	30.1
5	24.7	24.9	25.6	17	25.7	26.8	30.4
6	24.6	24.8	25.3	18	25.8	26.8	28.5
7	24.5	24.7	25.2	19	25.8	26.7	28.2
8	24.5	24.8	27.1	20	25.8	26.5	27.8
9	24.5	25.0	27.6	21	25.7	26.4	27.6
10	24.5	25.2	28.0	22	25.6	26.3	27.4
11	24.6	25.4	28.4	23	25.5	26.1	27.0
12	24.7	25.5	28.7	24	25.2	25.8	26.8

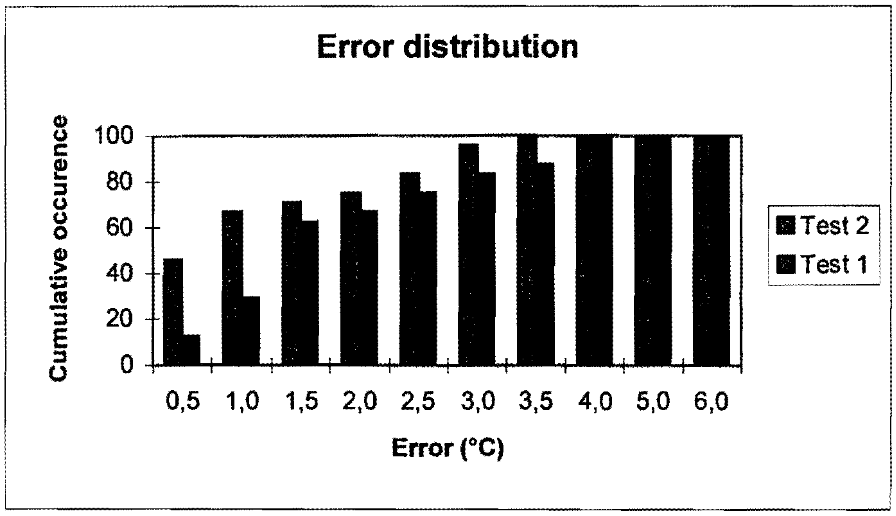




STUDY 92

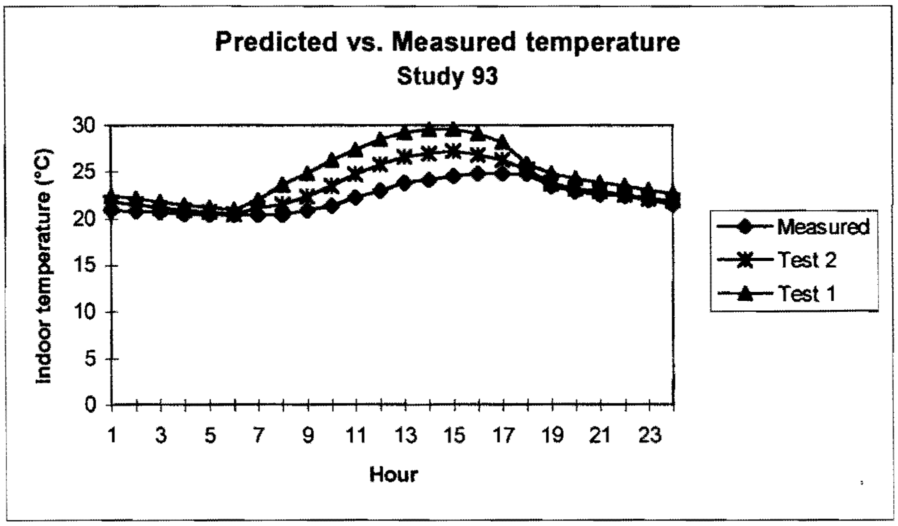
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	19.5	19.4	20.4	13	21.6	24.4	25.2
2	19.3	19.2	20.2	14	21.9	24.9	25.6
3	19.2	18.9	19.8	15	22.1	25.3	25.8
4	19.1	18.6	19.5	16	22.1	25.0	25.4
5	19.1	18.4	19.3	17	22.1	24.3	24.4
6	19.1	18.4	19.1	18	21.7	22.9	23.2
7	19.0	19.0	19.8	19	20.9	21.5	22.3
8	19.0	19.2	20.1	20	20.5	20.9	21.8
9	19.0	20.0	20.9	21	20.1	20.6	21.5
10	20.1	21.0	22.2	22	20.0	20.2	21.3
11	20.5	22.4	23.2	23	19.7	19.8	20.9
12	21.3	23.5	24.3	24	19.6	19.6	20.6

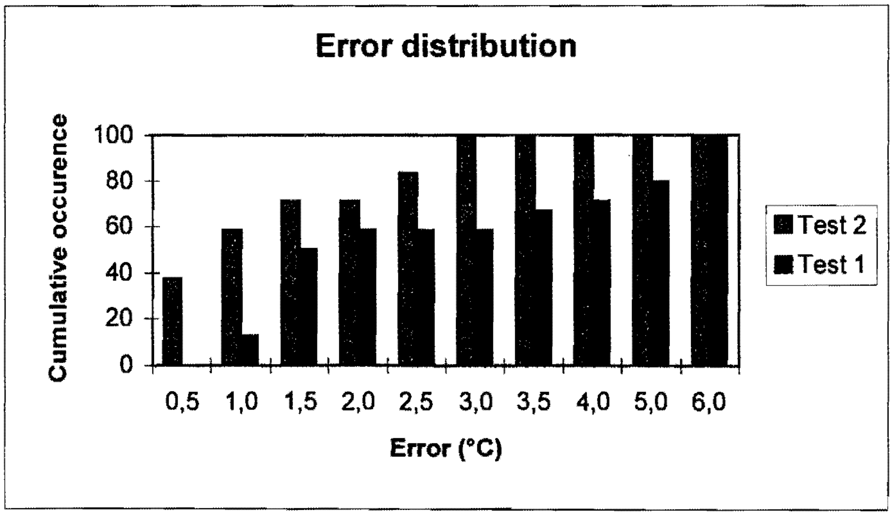




STUDY 93

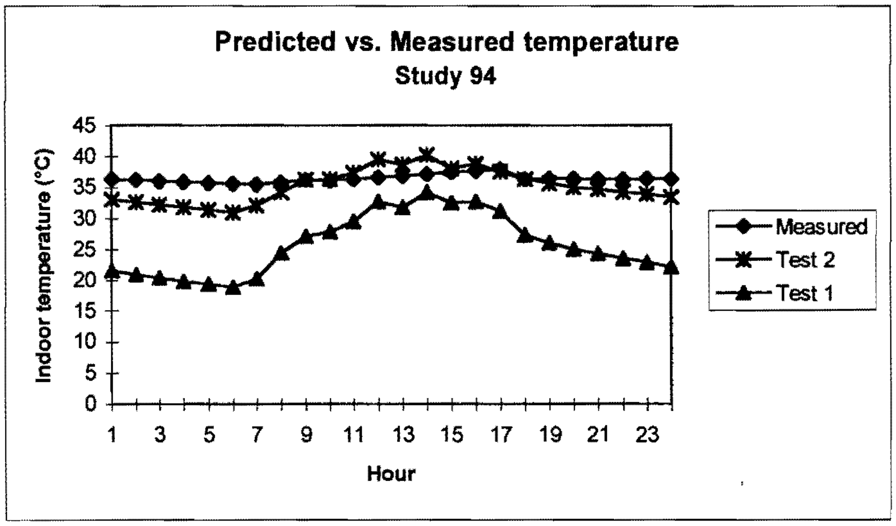
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	20.9	21.7	22.4	13	23.8	26.6	29.3
2	20.8	21.5	22.2	14	24.1	27.0	29.6
3	20.7	21.2	21.8	15	24.5	27.2	29.6
4	20.5	20.9	21.5	16	24.8	26.8	29.1
5	20.4	20.7	21.2	17	24.8	26.3	28.2
6	20.4	20.5	20.9	18	24.7	25.2	25.9
7	20.4	21.2	22.0	19	23.5	23.8	24.8
8	20.4	21.6	23.6	20	22.9	23.2	24.2
9	20.9	22.4	24.8	21	22.6	22.9	23.8
10	21.4	23.4	26.3	22	22.4	22.6	23.5
11	22.3	24.8	27.4	23	22.0	22.1	23.1
12	23.0	25.7	28.5	24	21.5	21.9	22.7

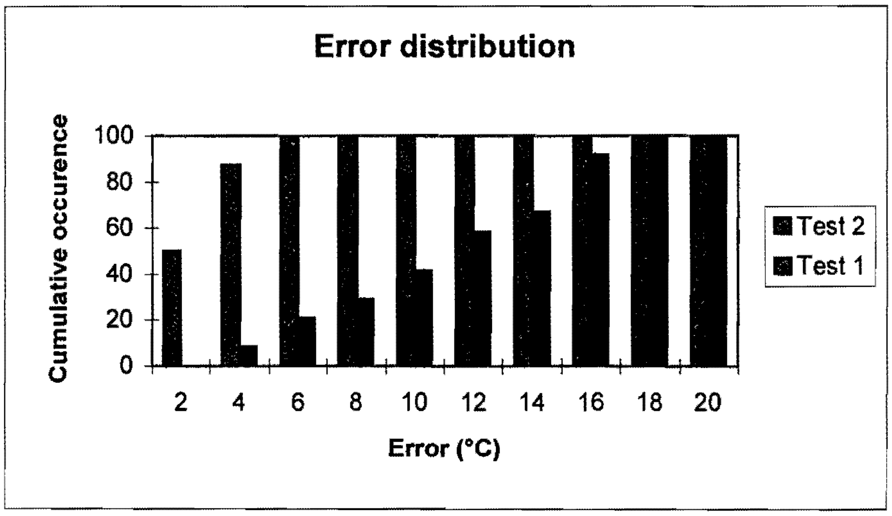




STUDY 94

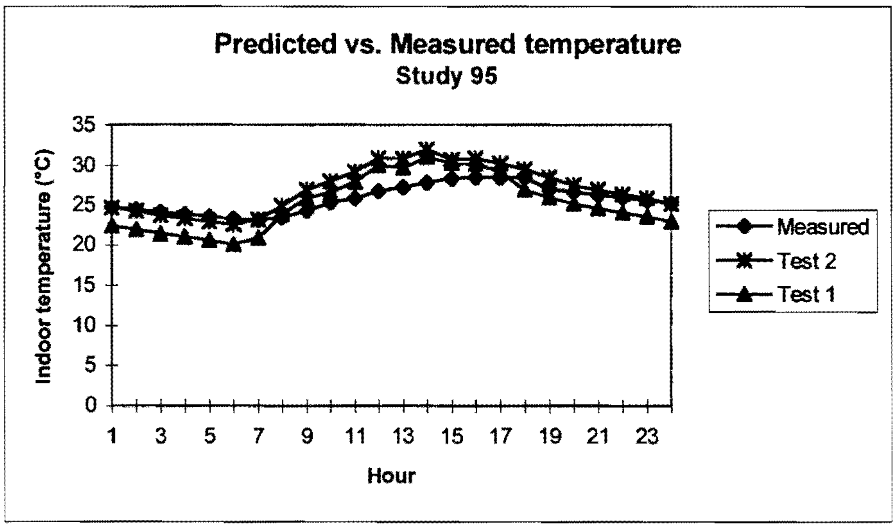
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	36.3	33.1	21.6	13	36.8	38.6	31.7
2	36.2	32.7	21.0	14	37.1	40.3	34.2
3	35.9	32.2	20.4	15	37.4	38.0	32.5
4	35.8	31.8	19.8	16	37.7	38.8	32.7
5	35.6	31.4	19.3	17	38.0	37.5	31.1
6	35.5	30.9	18.8	18	36.3	36.2	27.3
7	35.4	32.1	20.2	19	36.3	35.6	26.1
8	35.7	34.2	24.3	20	36.3	35.1	25.0
9	36.1	36.2	27.1	21	36.3	34.7	24.3
10	36.0	36.2	27.8	22	36.3	34.3	23.6
11	36.2	37.3	29.5	23	36.3	34.0	22.9
12	36.6	39.5	32.7	24	36.3	33.5	22.2

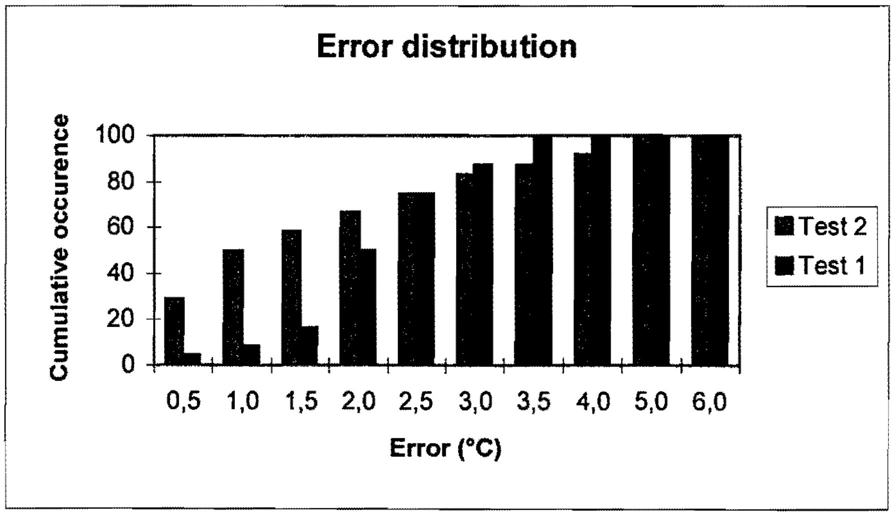




STUDY 95

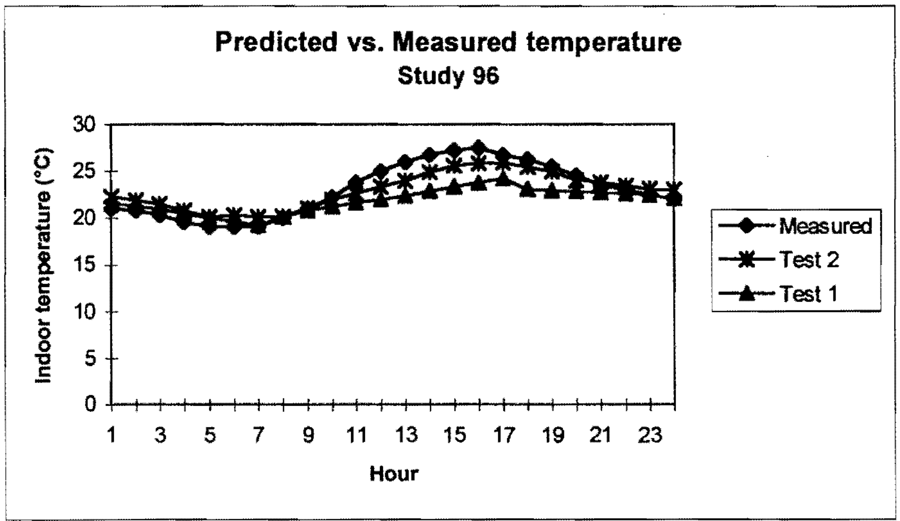
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	24.7	24.6	22.4	13	27.2	30.9	29.7
2	24.4	24.2	21.9	14	27.8	32.0	31.1
3	24.1	23.7	21.4	15	28.3	30.7	30.2
4	23.8	23.3	21.0	16	28.4	30.9	30.2
5	23.5	22.8	20.5	17	28.4	30.3	29.3
6	23.3	22.5	20.1	18	28.4	29.5	26.9
7	23.1	23.2	20.9	19	27.0	28.4	25.9
8	23.4	24.9	23.8	20	26.6	27.5	25.1
9	24.2	26.9	25.8	21	26.2	26.9	24.6
10	25.3	28.0	26.6	22	25.9	26.3	24.0
11	25.9	29.1	27.8	23	25.5	25.8	23.5
12	26.8	30.9	30.0	24	25.2	25.1	22.9

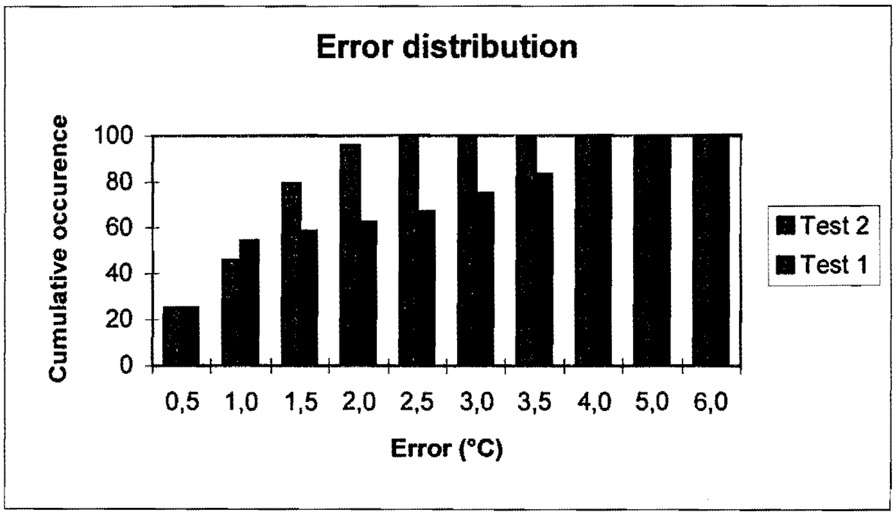




STUDY 96

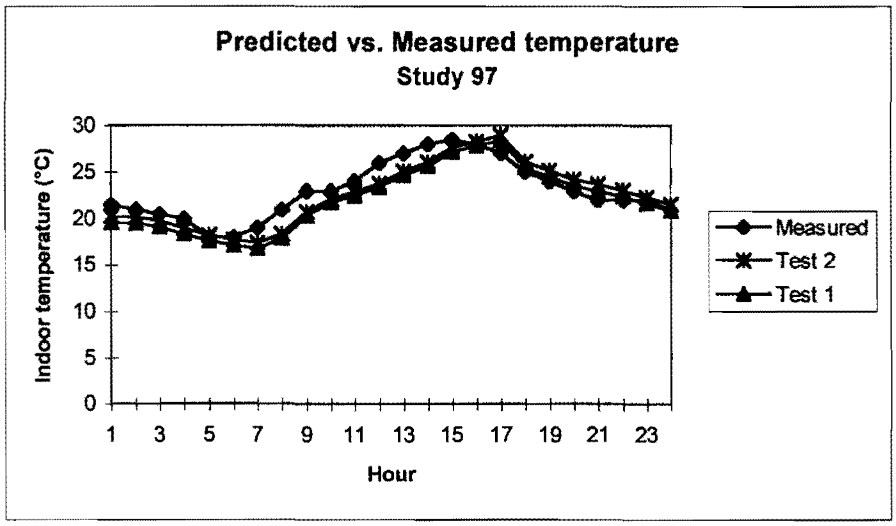
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.0	22.3	21.5	13	26.0	24.0	22.4
2	20.8	21.9	21.3	14	26.8	24.9	22.9
3	20.3	21.5	20.9	15	27.3	25.5	23.3
4	19.5	20.8	20.4	16	27.5	25.9	23.8
5	19.0	20.1	19.9	17	26.8	25.9	24.2
6	19.0	20.3	19.6	18	26.3	25.5	23.1
7	19.0	20.1	19.1	19	25.5	24.9	22.9
8	20.0	20.1	20.1	20	24.5	24.1	22.8
9	21.0	21.0	20.8	21	23.5	23.7	22.7
10	22.3	21.9	21.2	22	23.0	23.4	22.6
11	23.8	22.7	21.6	23	22.5	23.0	22.4
12	25.0	23.3	21.9	24	22.0	23.0	22.1

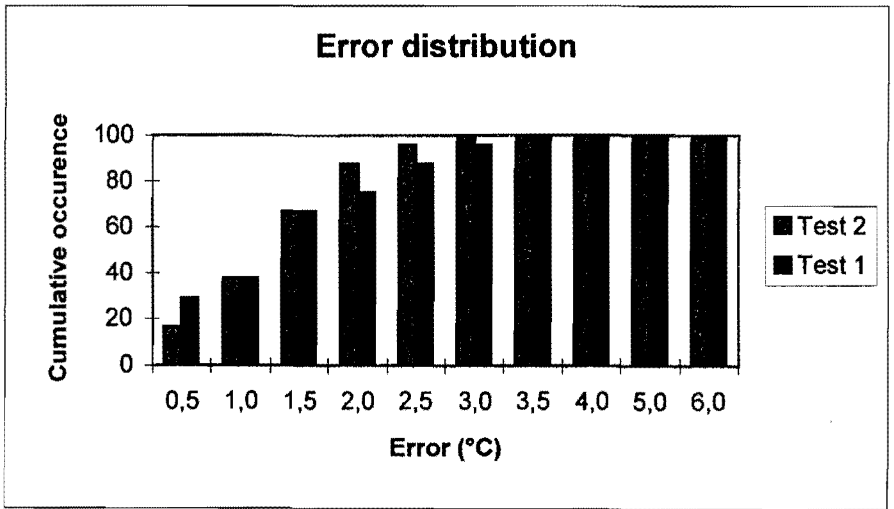




STUDY 97

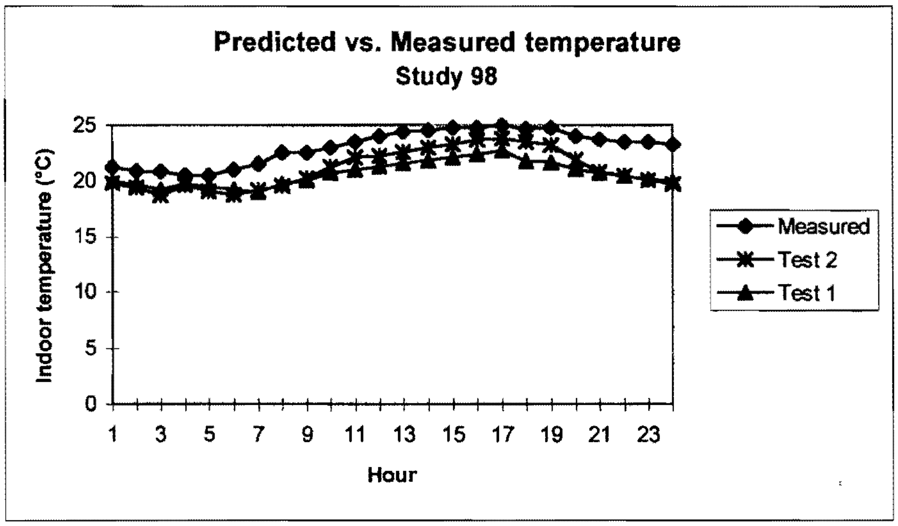
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.5	20.3	19.6	13	27	25.1	24.7
2	21	20.2	19.5	14	28	26.0	25.6
3	20.5	19.8	19.1	15	28.5	27.6	27.1
4	20	18.9	18.3	16	28	28.3	27.8
5	18	18.2	17.6	17	27	29.0	28.4
6	18	17.7	17.1	18	25	26.1	25.5
7	19	17.4	16.8	19	24	25.2	24.5
8	21	18.3	17.8	20	23	24.2	23.5
9	23	20.8	20.4	21	22	23.7	23.0
10	23	22.2	21.8	22	22	23.1	22.4
11	24	22.9	22.5	23	22	22.4	21.7
12	26	23.8	23.4	24	21	21.6	20.9

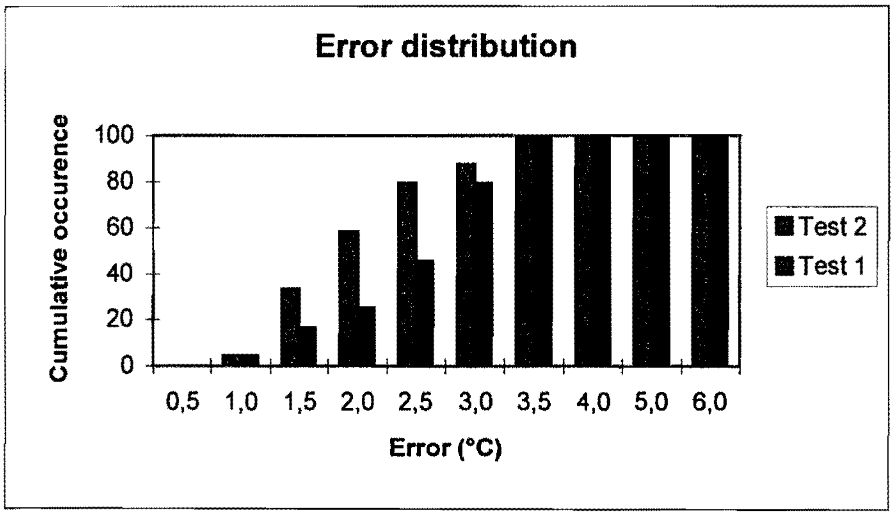




STUDY 98

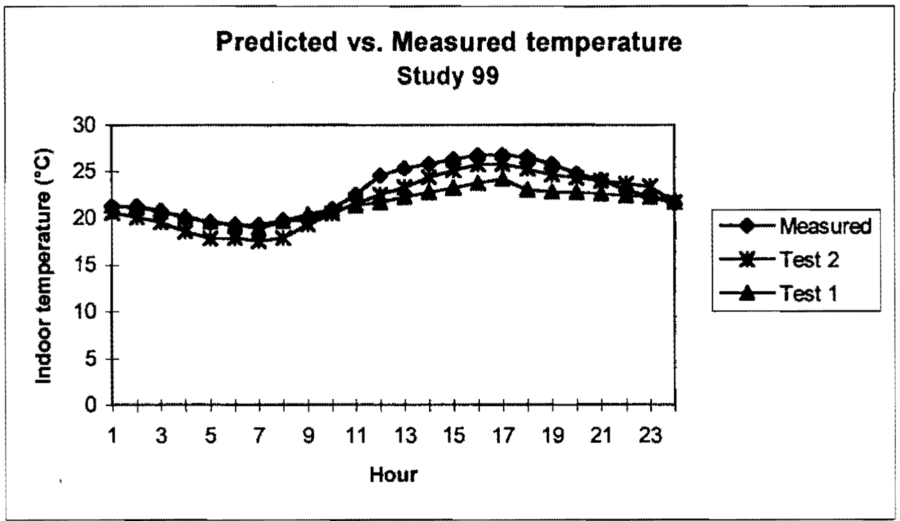
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.3	19.8	20.0	13	24.4	22.6	21.6
2	20.9	19.4	19.7	14	24.6	23.0	21.8
3	20.9	18.7	19.2	15	24.8	23.3	22.1
4	20.5	19.6	19.8	16	24.8	23.7	22.4
5	20.5	19.1	19.4	17	25.0	23.8	22.7
6	21.0	18.8	19.2	18	24.7	23.5	21.8
7	21.5	19.2	19.0	19	24.8	23.2	21.6
8	22.5	19.6	19.7	20	24.0	21.9	21.1
9	22.5	20.3	20.0	21	23.8	20.9	20.7
10	23.0	21.3	20.7	22	23.5	20.5	20.5
11	23.5	22.1	21.0	23	23.5	20.1	20.2
12	24.0	22.2	21.3	24	23.3	19.8	20.0

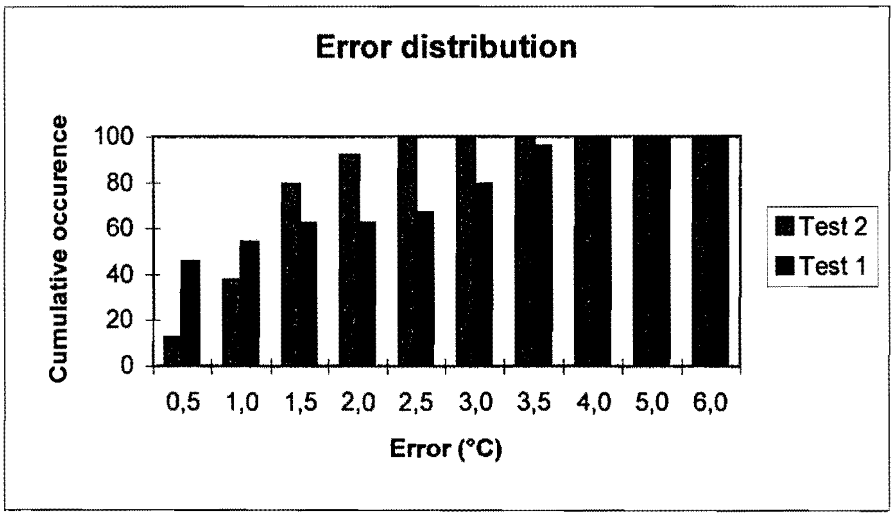




STUDY 99

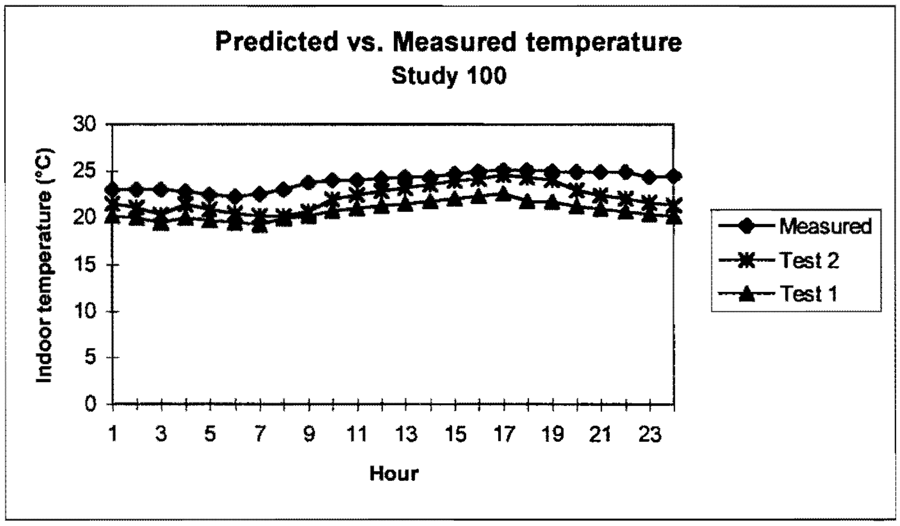
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	21.3	20.6	21.3	13	25.3	23.2	22.2
2	21.3	20.1	21.0	14	25.8	24.3	22.7
3	20.8	19.5	20.7	15	26.3	25.1	23.2
4	20.0	18.6	20.1	16	26.8	25.7	23.7
5	19.5	17.8	19.6	17	26.8	25.8	24.1
6	19.3	17.8	19.3	18	26.5	25.2	23.0
7	19.3	17.5	18.8	19	25.8	24.6	22.8
8	19.8	17.9	19.7	20	24.8	24.2	22.7
9	19.8	19.3	20.4	21	24.0	24.0	22.6
10	21.0	20.5	20.9	22	23.0	23.6	22.4
11	22.5	21.5	21.3	23	22.3	23.3	22.2
12	24.5	22.5	21.7	24	21.5	21.7	21.9

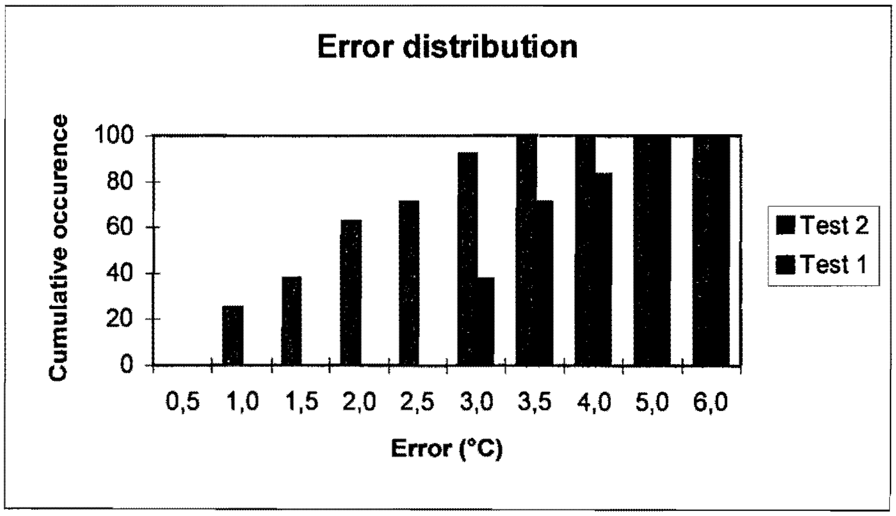




STUDY 100

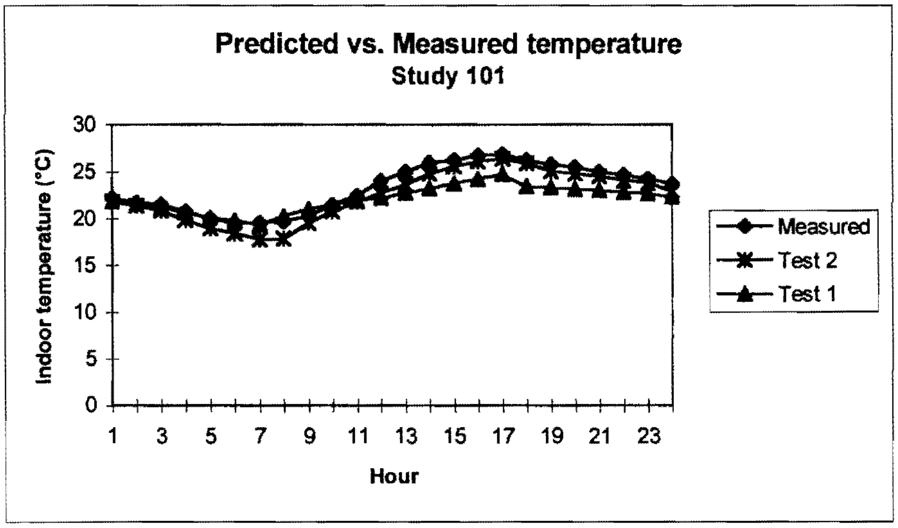
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.0	21.4	20.2	13	24.4	23.2	21.5
2	23.0	21.0	19.9	14	24.4	23.5	21.7
3	23.0	20.3	19.5	15	24.8	23.9	22.0
4	22.8	21.4	19.9	16	25.0	24.2	22.3
5	22.4	20.8	19.6	17	25.2	24.6	22.6
6	22.3	20.4	19.4	18	25.2	24.3	21.8
7	22.5	20.1	19.2	19	25.0	24.0	21.6
8	23.0	20.2	19.9	20	24.9	22.9	21.2
9	23.8	20.6	20.2	21	24.9	22.4	20.9
10	24.0	21.9	20.7	22	24.9	22.0	20.6
11	24.0	22.4	21.0	23	24.4	21.6	20.4
12	24.3	22.8	21.2	24	24.5	21.3	20.2

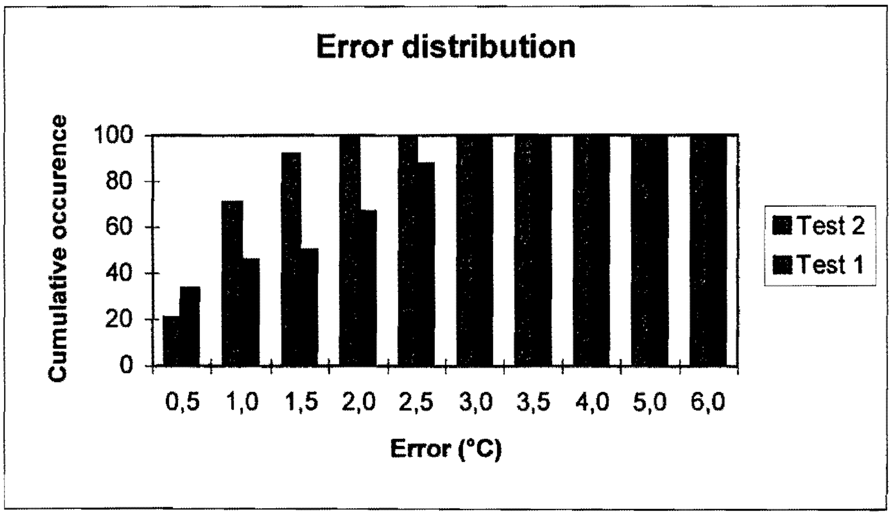




STUDY 101

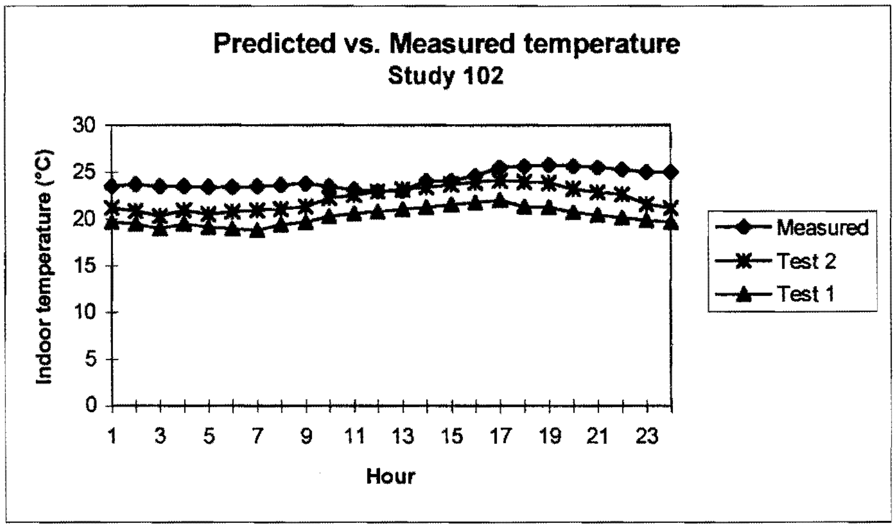
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	22.3	21.8	21.8	13	25.0	23.7	22.8
2	21.8	21.4	21.5	14	26.0	24.8	23.3
3	21.5	20.8	21.2	15	26.3	25.6	23.8
4	20.8	19.8	20.6	16	26.8	26.1	24.2
5	20.0	18.9	20.1	17	26.9	26.4	24.7
6	19.5	18.4	19.8	18	26.3	25.9	23.5
7	19.5	17.8	19.3	19	25.8	25.1	23.3
8	19.7	17.8	20.3	20	25.5	24.8	23.2
9	20.3	19.5	21.1	21	25.0	24.5	23.1
10	21.5	20.8	21.5	22	24.7	24.1	22.9
11	22.5	21.8	21.9	23	24.3	23.8	22.7
12	24.0	22.8	22.3	24	23.8	23.0	22.3

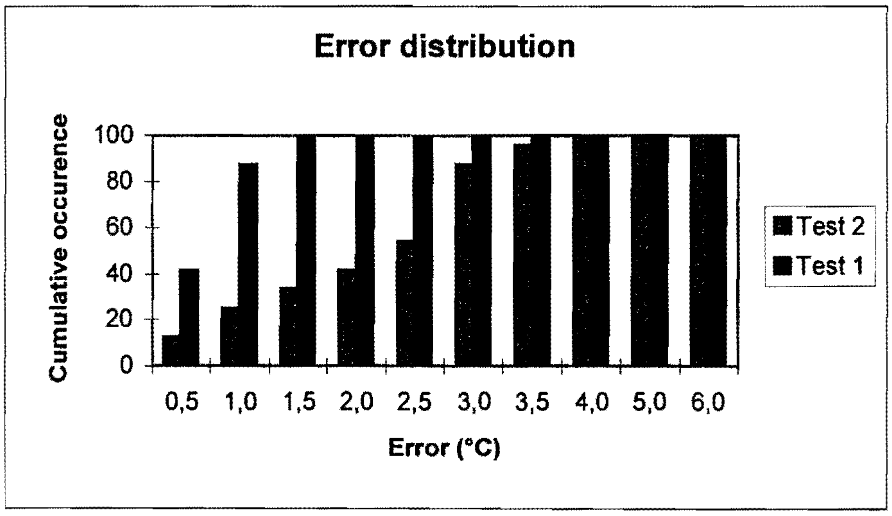




STUDY 102

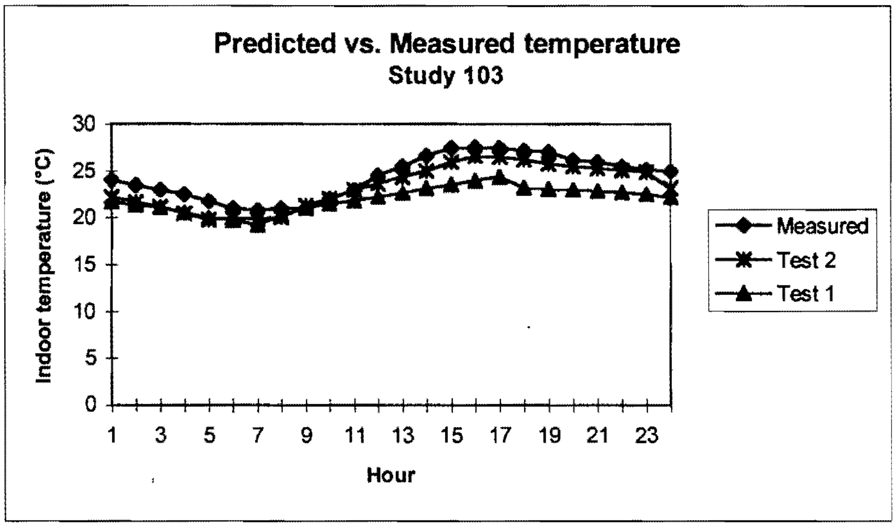
Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	23.5	21.2	19.7	13	23.0	23.1	21.0
2	23.7	20.9	19.4	14	24.0	23.4	21.3
3	23.5	20.3	19.0	15	24.0	23.7	21.5
4	23.5	20.9	19.5	16	24.6	23.9	21.8
5	23.4	20.5	19.1	17	25.5	24.1	22.0
6	23.4	20.8	18.9	18	25.7	24.0	21.3
7	23.5	20.9	18.7	19	25.8	23.8	21.2
8	23.6	21.1	19.4	20	25.6	23.2	20.7
9	23.8	21.3	19.6	21	25.5	22.9	20.4
10	23.5	22.2	20.3	22	25.3	22.6	20.2
11	23.1	22.6	20.5	23	25.0	21.6	19.9
12	23.0	22.9	20.8	24	25.0	21.2	19.7

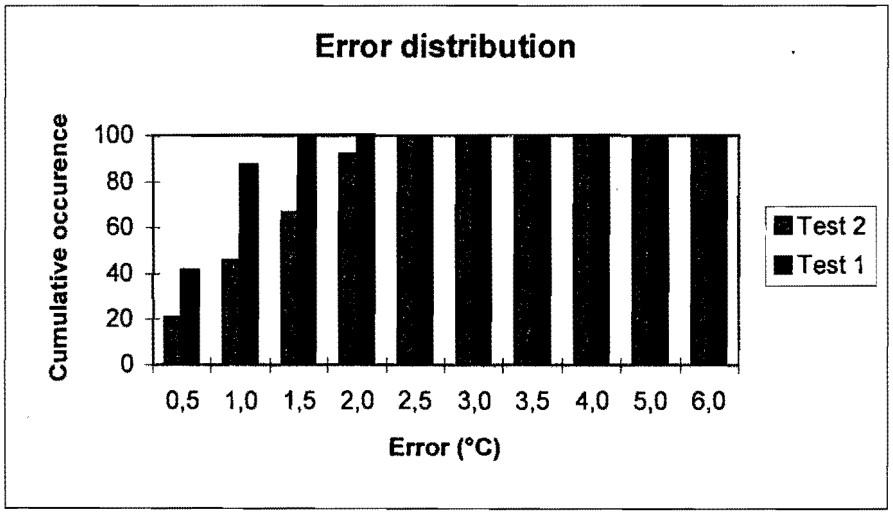




STUDY 103

Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]	Hour	Measured [°C]	Scenario 1 [°C]	Scenario 2 [°C]
1	24.0	22.3	21.6	13	25.5	24.4	22.7
2	23.5	21.7	21.4	14	26.7	25.0	23.1
3	23.0	21.1	21.0	15	27.5	26.0	23.6
4	22.5	20.4	20.5	16	27.6	26.6	24.0
5	21.8	19.7	20.0	17	27.5	26.5	24.4
6	21.0	19.9	19.7	18	27.3	26.3	23.2
7	20.8	19.8	19.2	19	27.1	25.8	23.1
8	21.0	20.0	20.2	20	26.2	25.5	23.0
9	21.0	21.2	21.0	21	26.0	25.3	22.9
10	22.0	22.0	21.5	22	25.5	25.0	22.7
11	23.0	23.0	21.8	23	25.2	24.9	22.5
12	24.5	23.7	22.2	24	24.9	23.1	22.2





Appendix D

SELECTION MATRIX

Air-conditioning system	Building Restrictions				Aesthetic Limitations				System Requirements				
	W_{A1} 5.5	W_{A2} 2.7	W_{A3} 0	W_{A4} 5.6	W_{B1} 2.7	W_{B2} 5.5	W_{B3} 0	W_{B4} 0	W_{C1} 2.6	W_{C2} 5.8	W_{C3} 5.8	W_{C4} 5.2	W_{C5} 5.2
All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	22.0	5.5	0.0	27.5	13.7	27.5	0.0	0.0	13.1	0.0	23.0	0.0	5.2
All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	22.0	5.5	0.0	27.5	13.7	27.5	0.0	0.0	13.1	0.0	28.8	0.0	5.2
All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	22.0	4.1	0.0	27.5	13.7	27.5	0.0	0.0	13.1	0.0	23.0	0.0	5.2
All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	22.0	4.1	0.0	27.5	13.7	27.5	0.0	0.0	13.1	0.0	28.8	0.0	5.2
All-air, dual duct system with water-cooled refrigeration plant.	22.0	0.0	0.0	27.5	11.0	27.5	0.0	0.0	13.1	0.0	17.3	5.2	10.5
All-air, dual duct system with air-cooled refrigeration plant.	22.0	0.0	0.0	27.5	11.0	27.5	0.0	0.0	13.1	0.0	23.0	5.2	10.5
All-air, variable volume, economiser system and water- cooled refrigeration plant.	22.0	2.7	0.0	27.5	8.2	27.5	0.0	0.0	10.5	0.0	17.3	10.5	10.5
All-air, variable volume, economiser system and air-cooled refrigeration plant.	22.0	2.7	0.0	27.5	8.2	27.5	0.0	0.0	10.5	0.0	23.0	10.5	10.5
Four-pipe system with air-cooled refrigeration plant.	22.0	8.2	0.0	22.0	5.5	27.5	0.0	0.0	7.9	0.0	23.0	15.7	15.7
Four-pipe system with water-cooled refrigeration plant.	22.0	8.2	0.0	22.0	5.5	27.5	0.0	0.0	7.9	0.0	17.3	15.7	15.7
Two-pipe system with air-cooled refrigeration plant.	22.0	11.0	0.0	22.0	5.5	27.5	0.0	0.0	7.9	0.0	17.3	15.7	5.2
Two-pipe system with water-cooled refrigeration plant.	22.0	11.0	0.0	22.0	5.5	27.5	0.0	0.0	7.9	0.0	11.5	15.7	5.2
Split systems	22.0	11.0	0.0	16.5	2.7	27.5	0.0	0.0	7.9	23.0	17.3	20.9	20.9
Window units	27.5	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.8	0.0	26.2	26.2
Through the wall console units	27.5	13.7	0.0	0.0	0.0	27.5	0.0	0.0	0.0	28.8	0.0	26.2	26.2
Packaged rooftop units	22.0	4.1	0.0	27.5	13.7	27.5	0.0	0.0	13.1	11.5	28.8	0.0	5.2

Table D.1 - Selection matrix

Air-conditioning system	Air Quality and flow Restrictions					Building Management				Cost	Preliminary		**System**
	W_{D1} 2.9	W_{D2} 0	W_{D3} 5.8	W_{D4} 5.8	W_{D5} 2.9	W_{E1} 5.8	W_{E2} 5.8	W_{E3} 5.8	W_{E4} 6.3	W_F 7.3	W_{G1} 5.2	W_{G2} 0	**Ranking Value**
All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	14.4	0.0	28.8	28.8	14.4	28.8	0.0	0.0	31.4	10	5.2	0.0	**300**
All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	14.4	0.0	28.8	28.8	14.4	28.8	0.0	0.0	31.4	11	5.2	0.0	**306**
All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	14.4	0.0	28.8	28.8	14.4	28.8	0.0	0.0	31.4	23	5.2	0.0	**311**
All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	14.4	0.0	28.8	28.8	14.4	28.8	0.0	0.0	31.4	26	5.2	0.0	**320**
All-air, dual duct system with water-cooled refrigeration plant.	14.4	0.0	28.8	28.8	14.4	28.8	0.0	0.0	0.0	22	5.2	0.0	**276**
All-air, dual duct system with air-cooled refrigeration plant.	14.4	0.0	28.8	28.8	14.4	28.8	0.0	0.0	0.0	24	5.2	0.0	**284**
All-air, variable volume, economiser system and water- cooled refrigeration plant.	14.4	0.0	28.8	23.0	14.4	28.8	0.0	5.8	18.8	9	5.2	0.0	**285**
All-air, variable volume, economiser system and air-cooled refrigeration plant.	14.4	0.0	28.8	23.0	14.4	28.8	0.0	5.8	18.8	31	5.2	0.0	**313**
Four-pipe system with air-cooled refrigeration plant.	8.6	0.0	17.3	17.3	8.6	17.3	17.3	17.3	12.6	25	5.2	0.0	**293**
Four-pipe system with water-cooled refrigeration plant.	8.6	0.0	17.3	17.3	8.6	17.3	17.3	17.3	12.6	0	5.2	0.0	**263**
Two-pipe system with air-cooled refrigeration plant.	8.6	0.0	17.3	17.3	8.6	11.5	17.3	17.3	18.8	34	5.2	0.0	**290**
Two-pipe system with water-cooled refrigeration plant.	8.6	0.0	17.3	17.3	8.6	11.5	17.3	17.3	18.8	11	5.2	0.0	**261**
Split systems	0.0	0.0	0.0	0.0	5.8	5.8	28.8	28.8	12.6	23	5.2	0.0	**279**
Window units	0.0	0.0	0.0	0.0	0.0	0.0	28.8	28.8	0.0	28	0.0	0.0	**208**
Through the wall console units	0.0	0.0	0.0	0.0	0.0	0.0	28.8	28.8	0.0	28	0.0	0.0	**235**
Packaged rooftop units	8.6	0.0	23.0	28.8	11.5	23.0	0.0	0.0	25.1	37	5.2	0.0	**316**

Table D.1 - Selection matrix (Continued)

D.1 NOTES

1. The above matrix provides the detail selection results of the hypothetical building of Chapter 7.
2. The matrix indicates the product of the weighing factor and rating factor for each system and its corresponding selection criteria. The total of which is provided in the system ranking value column.
3. The weighing factor (W_i) for each selection criteria is provided at the top of the matrix.
4. Refer to Chapter 6 for the appropriate rating factors.