Climatic Responsive Design & Occupant Comfort: The Case Of The Atrium Building In A Mediterranean Climate

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"The space within becomes the reality of the building"

Frank Lloyd Wright

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ABSTRACT

Atria, particularly those enclosed by glass, have become popular features of many buildings in recent years. Due to the large amount of glazing, they are characterised by complex thermal processes and by levels of interaction with the ambient climate more intense than other types of buildings. Both the thermal processes and the local climate, place additional complexity for the designer of an atrium building.

So far, research concerning atrium buildings and glazed spaces has focused on their energy performance and their potential contribution in minimizing cooling and heating loads of the adjacent buildings. The current research additionally concentrates on the need to achieve acceptable indoor thermal conditions, basic condition for environmental control of a space. However, the knowledge concerning occupant expectations and preferences in atrium buildings is limited, especially regarding warm to hot climates i.e. the Mediterranean climate.

The research comprises the study of factors influencing temperature in glazed atrium spaces in Mediterranean climate and the conditions that result in relation to occupant comfort. The investigation involved:

- literature review on atrium architectural forms and thermal processes;
- observations of atrium buildings in the specific climatic context;
- thorough analysis of the climate and climatic responsive design strategies;
- occupant comfort surveys;
- in situ physical measurements of a case study building in Greece during the peak seasons (winter and summer);
- empirical validation of the software.

The results from the occupant comfort survey established the adaptability of the users to a wider range of thermal conditions in atrium buildings. The in situ physical measurements provided useful information on the building's performance. These results and the background research constituted a valuable input for the parametric study from which recommendations of design criteria for optimal atrium design in the Mediterranean climate were derived.

The main conclusion of the research is that understanding the climatic attributes of a specific location, and the occupants' expectations, together with the selection of appropriate design parameters, leads to the design of a comfortable and efficient environment. The results of the study are applicable to designers at the conceptual stage as well as to cases of retrofitting.

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CHAPTER 1

INTRODUCTION

1.1 Research area

In recent years atria, particularly those enclosed by glass, have become popular features of many buildings. The additional protection afforded to what would otherwise be external circulation spaces helps provide a more controlled environment. In Northern Europe atria are promoted as transforming external spaces to have environmental conditions closer to those of the Mediterranean. Atria have also become popular in warmer climates, but not always successfully, as in summer they could result in excessive overheating. Therefore, in order to design comfortable as well as energy efficient buildings, it is rather important to consider the climatic context as well as the occupants' needs.

The potential energy savings of atria have been widely acknowledged and discussed the past few decades. Historically, atria were uncovered, internal spaces (courtyards), within dwellings in Southern Europe. They provided a temperate climate and were valued as protected private spaces. Modern atria became popular in the 1960's, had a rapid development during the 1970's, as large scale atria began to be incorporated into office and hotel buildings as amenity spaces with external qualities. The energy crisis of the 1970's raised the profile environmental issue and the potential for use of the atrium as a buffer space to reduce the energy consumption has received attention since then: not only aesthetics, but also energy efficiency principles are expected to be embodied in order to create comfortable spaces.

The atrium today serves a very important function as a point of contact between architecture and the city. At the scale of the city, transitional spaces play a major role in the energy efficiency of parent buildings but more interestingly, by avoiding discomfort through progressive environmental transients, they also encourage the optimal receptivity of the pedestrians to their built and social environments.

Indeed, a review of historical examples and modern case studies suggests that atria serve many functions in a variety of building types. In addition to aesthetic, social, cultural and economic functions, a primary intent in many modern buildings is to use the atrium as a climate-modulating or thermal buffer zone to make "outdoor" space more comfortable and usable for more time during the year.

However, when designing in a Mediterranean climate, overheating during the summer months and potential for excessive heat loss during the winter months are some of the concerns addressed. The thermal performance of an atrium and its adjoining spaces is complex; it depends on its orientation and geometry, the character of its wall and floor surfaces, the nature of its roof and glazing, and the penetration of daylight into adjoining spaces. This results in complex interfacing of cooling, heating and ventilating. Additional to that, the occupants' thermal expectations play a significant role in its energy requirements and it is therefore worthy of investigation.

1.2 The work of others

Large glazed spaces and atria are now widely constructed, which means that there is a need for guidelines and different types of design tools. Over the past 10-15 years, a lot of research and studies of different kinds have been carried out and described in research reports and handbooks.

Richard Saxon and Michael Bednar were the forerunners, showing many examples of atrium buildings. Richard Saxon in his books (Atrium Buildings: Development and Design, and The Atrium Comes of Age) provides a summary of the history of the modern atrium and includes a gazetteer of notable atrium buildings in the UK, France, Scandinavia, USA, Canada, Australia, Hong Kong and Japan. The book by Michael Bednar (The New Atrium) is structured to illustrate key building types: hotels, shopping and leisure developments, office buildings, public buildings and multi-use structures and also to provide a summary of developments in all key design aspects of atria including environment, structure, vertical transport and economics.

Glazed spaces have also been studied by the International Energy Agency [IEA], while the American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. [ASHRAE] has incorporated a section with guidelines on atrium buildings in its handbook.

Work on design aids with respect to climate and energy requirements has started in a number of countries, mainly in North Europe. Kainlauri and Vilmain [1995] conducted a survey on atrium research to develop design criteria that focused on atrium orientation, building envelope, heating, ventilation and air-conditioning system and indoor thermal environment. Mills [1994] reviewed completed atrium research projects in Europe and compiled design strategies that focused on the incorporation of passive solar principles into the atrium design. Yoshino et al. [1995] reviewed atrium research in Japan, and identified common trends in the design of the indoor thermal environment and the construction of atrium buildings. Bryn [1995] presented a historical development of atrium buildings and discussed design aspects from the perspective of atrium function, indoor thermal environment and energy use.

Computer simulation programmes were also used in past and more recent studies to investigate the impact of design strategies and climatic context on thermal performance and energy use of atrium buildings. Duke [1983] compared the energy cost of a building with an open courtyard and a building with a glazed courtyard using the DOE programme (hourly, whole-building energy analysis programme calculating energy performance and life-cycle cost of operation). The author concluded that adding a glazed roof to an open courtyard resulted in energy savings of about 10%. Landsberg et al. [1986] investigated the impact of a wide range of design strategies on the energy performance of atrium buildings. Atif [1992] used the TRNSYS programme to investigate the impact of the top-fenestration and wall mass area on daylighting and cooling of atrium buildings in warm climates. One of his overall recommendations for further research was the study of the human appraisal in atria. Wall [1996], with the aid of a steady state computer programme, investigated the influence of the design options on the climate and energy requirements of three types of atrium buildings. In the same line, Ho [1996], investigated the relationship between atrium design and different climatic conditions in Europe with particular emphasis to certain parameters with a potential to form climatic responsive and energy efficient atrium buildings. Izard and Frusta [1998] performed thermal simulations of linear atria with FLUENT in order to investigate thermal stratification in relation to architectural design.

As seen in the previous paragraphs, a wide aspect of atrium buildings' characteristics and issues of energy and thermal performance have been covered and analysed. However, very little research has been done for atrium buildings in a context of a climate like the Mediterranean and in relation to its thermal performance and the impact on occupants' comfort. There are a large number of research and field studies on thermal comfort expectations of people in their living or working environment, but relatively little knowledge exists on how people expect to feel in an atrium space, which is neither "inside" nor "outside". According to many researchers there still is a lack of knowledge regarding the human appraisal of atria and of guidelines for the assessment of climate and occupants' comfort in a glazed space already at the preliminary design stage. The expectation of the thermal conditions inside the atrium, especially during the warm season, is of vital importance therefore the research concentrates on these problems.

1.3 Research Objectives

Having outlined the research area, the following paragraph summarises the major research objectives:

- To examine the modem atrium building forms, types and uses in the Mediterranean region.
- To assess the local climate in order to identify strategies for climatic responsive design.
- To investigate the occupants' comfort expectations in an atrium building in the Mediterranean climate.
- To investigate the thermal performance of an atrium building in a Mediterranean climate during peak weather conditions.
- To analyse the relationship between building design, climate and occupants' thermal comfort in atrium buildings.
- To identify the impact of selected design parameters in the atrium thermal performance and occupants' comfort.
- To provide design guidelines for the preliminary design stage for optimum thermal environment and occupant comfort of atrium buildings set in a Mediterranean climate.

This has been done in an effort to optimise both the comfort and the thermal performance of the whole building, particularly when set in a warm climate.

1.4 Research Procedure

As it has been stated in the research objectives, the research study ultimately concentrates on identifying the "optimum" atrium design for the Mediterranean climate, which will help devise guidelines for climatic design for atrium buildings in the specific climatic context. There are two basic questions to be answered before design strategies can be discussed. First, what is the climate of the site and secondly, what is the nature of the building use and how does it impact on thermal concerns. The climate is the obvious deciding factor: buildings in a climate like the Mediterranean generally need heat in winter and cooling in summer.

A further basic decision, before the strategy can be turned into a design, is on the degree of comfort required by the occupants in the atrium space itself. What constitutes a "comfortable" thermal environment? The answer to this deceptively simple question has profound implications for the design and operation of buildings, the amount of energy required to heat and cool them and the resulting impact on the quality of both the natural and built environment.

This research thus combines thermal comfort and thermal performance studies because the two topics are interlinked in that buildings are designed in order to optimise their performance. The principle idea is that if a building is poor in thermal performance it should be reflected in the occupant's high level of dissatisfaction and vice versa.

Selected parameters of atrium building design will be analysed in a parametric study. Some of these parameters are determined early in the design stage, which means that the climate in the glazed space as well as the energy requirements will also be indirectly determined at an early stage.

1.5 Questions & Hypothesis

The previous review suggests the following research questions and hypotheses:

- If no heating, ventilation and air-conditioning is used in the atrium space, which strategies give best comfort?

- Would the atrium have provided better thermal comfort conditions varying selected design alternatives such as geometry, ventilation mode, roof glazing material or even ambient climate?
- Are the above variations of the atrium design connected with local discomfort (to examine the variation in comfort in various spots and heights within an atrium).

Hypothesis: Atrium buildings in Mediterranean climate can contribute to the overall energy requirements for heating and cooling while achieving acceptable thermal comfort conditions for the occupants.

The energy requirement of a building depends largely (apart from the climate) on the occupants' comfort requirements. It is therefore vital to recognise the expectations of the occupants and design accordingly.

1.6 Methodology

This paragraph outlines the methodology employed in the current research in order to achieve the above research goals.

The current research focuses around two main topics i.e. thermal performance and thermal comfort of atrium buildings in a Mediterranean climate. Due to the particular nature of the study, several methodologies were reviewed and adopted. These are discussed in more detail in the relevant chapters.

Several case studies in Mediterranean climate were visited and observed in order to help identify the general forms, types and uses as well as problems of glazed spaces. An atrium building in a Mediterranean climate was selected as a detailed case study. Field thermal comfort surveys with the occupants of the building with simultaneous physical measurements of internal conditions were conducted for several weeks during cool and warm season. The results were analysed using statistical methods.

Measurements of the atrium internal conditions were conducted for both seasons and analysed in comparison to the ambient climatic conditions for the same period. The analysis of the results from the physical measurements was used as a preliminary study and some of the data were used to verify what would be done next. Extensive climatic data was analysed in order to provide climatic responsive strategies and as an input for the parametric analysis.

Schematic Approach to Methodology

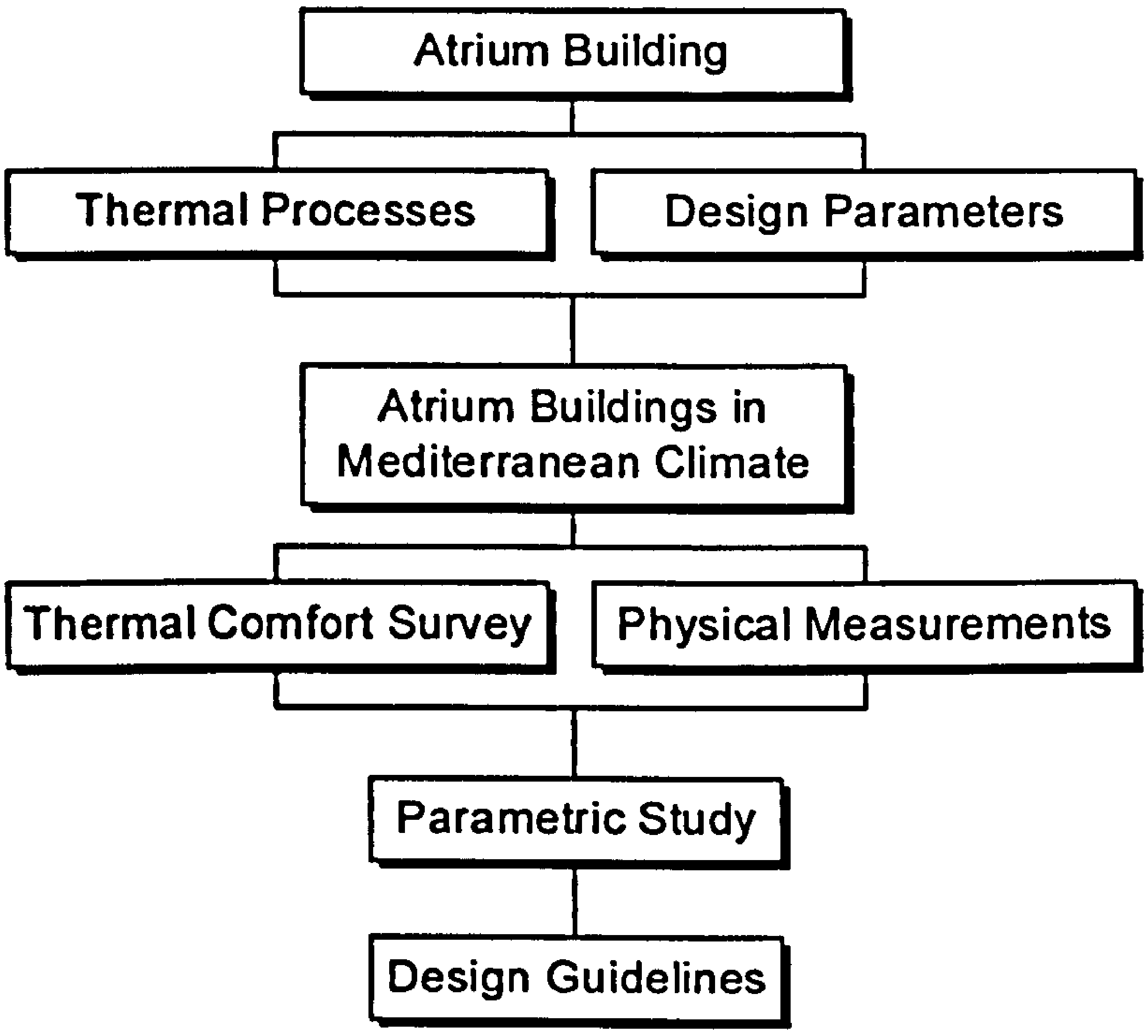


Figure 1.1: A schematic approach to the methodology of the thesis.

At the last stage of the research, a dynamic thermal simulation programme was employed and validated through the measured data. Having validated the computer model against the actual data, the next stage was the parametric study where selected design alternatives were analysed and assessed in order to draw general guidelines for the design of atrium buildings in a Mediterranean climate. Figure 1.1 shows a schematic approach to the methodology of the thesis.

1.7 Thesis Layout

The thesis is organised in seven chapters divided in 3 parts: the first part (chapters 1, 2 & 3) provides an investigation of the key issues relevant to the current research i.e. atrium buildings, Mediterranean climate, energy issues and thermal comfort. It sets the background and context of the research area, the basis of the problem statement and motivation. The second part (chapters 4 & 5) consists of the presentation, analysis and interpretation of the results of the field study and the validation of the selected simulation software. The third part (chapters 6 & 7) is the analysis and discussion of the results of the parametric study, which form the design guidelines for climatic responsive atrium design and occupant comfort in a Mediterranean climate. A more detailed presentation of the content of each chapter is given in the following paragraphs.

Chapter 1 is a brief introduction to the research area, the thesis objectives, the methodology and its contents.

Chapter 2 gives on background information on the research content; the atrium building and thermal comfort. The first part of the chapter focuses on the main type of building under investigation, the atrium. It starts off with a literature review on atrium buildings and its historical development as a building type, its functions as a space, and the description of generic forms of atrium buildings. The next paragraphs concentrate on the energy issues associated with atrium buildings and in more detail looks into atria in Mediterranean climate through examples of existing buildings in Greece and other countries of the Mediterranean basin. The last part of the chapter is a brief introduction to thermal comfort, thermal comfort parameters and explains why it is important for this research to investigate thermal comfort.

Chapter 3 provides a review of the definitions of climate and the use of psychrometric charts for climatic responsive design. The second part focuses on the analysis of the Mediterranean climate, with reference to Greece, the application of climatic zones and a detailed analysis of the case study climate.

Chapter 4 consists of two main parts: the first part looks into the thermal performance of an atrium building in the climatic context of Greece. The focus is mainly on the climatic performance of the building and the assessment of thermal performance. A one-week period was selected for each season in order to investigate climatic fluctuations inside the atrium space. The second part focuses on the use of a thermal simulation programme in order to model the building and to allow the comparison of measured and predicted data, which in this study was seen as the most suitable approach to validation of the programme for use in parametric studies.

Chapter 5 investigates the thermal conditions that occur in atrium buildings set in a Mediterranean climate as perceived by the users. The major part of this chapter concentrates on the thermal comfort survey in Greece, its design and limitations, followed by an analysis of the results and the establishment of thermal comfort limits for the occupants of the atrium building.

Chapter 6 presents the structure and design parameters of virtual atrium models and the analysis of the results from the parametric study using the thermal simulation programme. It also includes a tabulated form of the results summarised and a statistical analysis.

Finally, in Chapter 7 the findings of the current study are summarised and discussed and general guidelines for climatic responsive design and occupant comfort of atrium buildings in the Mediterranean climate are drawn. The chapter concludes with an outline of the contribution and limitations of the research and suggestions for further research in this area.

CHAPTER 2

RESEARCH CONTENT

2.1Introduction

This chapter gives the background to the work carried out in the thesis; the atrium building, starting with a historical review of such buildings, which leads on to, how they are designed today, particularly in the Mediterranean context, and concluding with background information on thermal comfort.

More specifically, the first part of the chapter focuses on the atrium building. It is divided into three sections: the first part is a literature review, with a definition of "atrium", its historical development as a building type, its functions as a space, and the description of generic forms of atrium buildings. The second part concentrates on the energy parameters associated with atrium buildings; there is a description of certain thermal processes connected with certain design factors, interlinked with the atrium's thermal behaviour as part of the designer's checklist. A selection of these factors will play a key role in the parametric study in a following chapter. The third part focuses on atrium buildings in Mediterranean climate through examples of existing atrium buildings in Greece and other countries of the Mediterranean basin.

The second part of the chapter provides background information on thermal comfort i.e. the thermal comfort parameters and why people need to be comfortable and explains why it is important for the current research to investigate thermal comfort.

2.2 The Atrium

2.2.1 Definition of "Atrium"

"*The word atrium refers originally to the open courtyard of a Roman house. Today, an atrium refers to a protected courtyard or glazed winter garden within a building*", [Watson, 1982].

A "courtyard" is a space within a building or between buildings that is open to the sky. An atrium is a covered, enclosed courtyard. The term "atrium" is currently used to describe covered spaces that extend to or border the exterior of buildings or occur between buildings. Another definition says that an atrium is "a space enclosed laterally by the walls of a building, and covered by transparent or translucent material".

The Roman "atrium" (the plural form "atriums" is occasionally used as an alternative to "atria") was in fact an open courtyard within a dwelling, and some authors use the word atrium to describe covered and uncovered spaces. Of course, it is difficult to consider the atrium apart from its parent building, hence the term, atrium building.

The recent confusion regarding the atrium has been identified partly as a problem of terminology, since there is no accurate definition. Scholar's of architecture have used the term *atrium* to refer to the Roman type and other terms, such as court, galleria, covered plaza, square, cortile, rotunda, pavilion, to refer to the new type, while at the same time referring to the space's function.

Different authors use these and other terms in different ways. For instance, [Lam, 1986] uses the terms "court", "atrium"," light- court", "litrium", and "light well" to make finer distinctions about the use and shape of the space.

The atrium is also defined as "*a focal indoor courtyard or plaza that its climate controlled and often more than one storey in height*" [Lehrman, 1984]. The actual atrium may be skylit, wholly enclosed by the building, or glazed on one or more sides.

In the area of architectural philosophy, the atrium is considered as a "*spatial expression of human activity, one that is created by simple means*" [Lehrman, 1984].

The modern atrium building can be described by the following physical characteristics:

1. Geometry
2. Location and orientation of glazing surfaces
3. Thermal characteristics of the skin separating the atrium from the environment

The basic physical characteristics of an atrium building are shown in Figure 2.1.

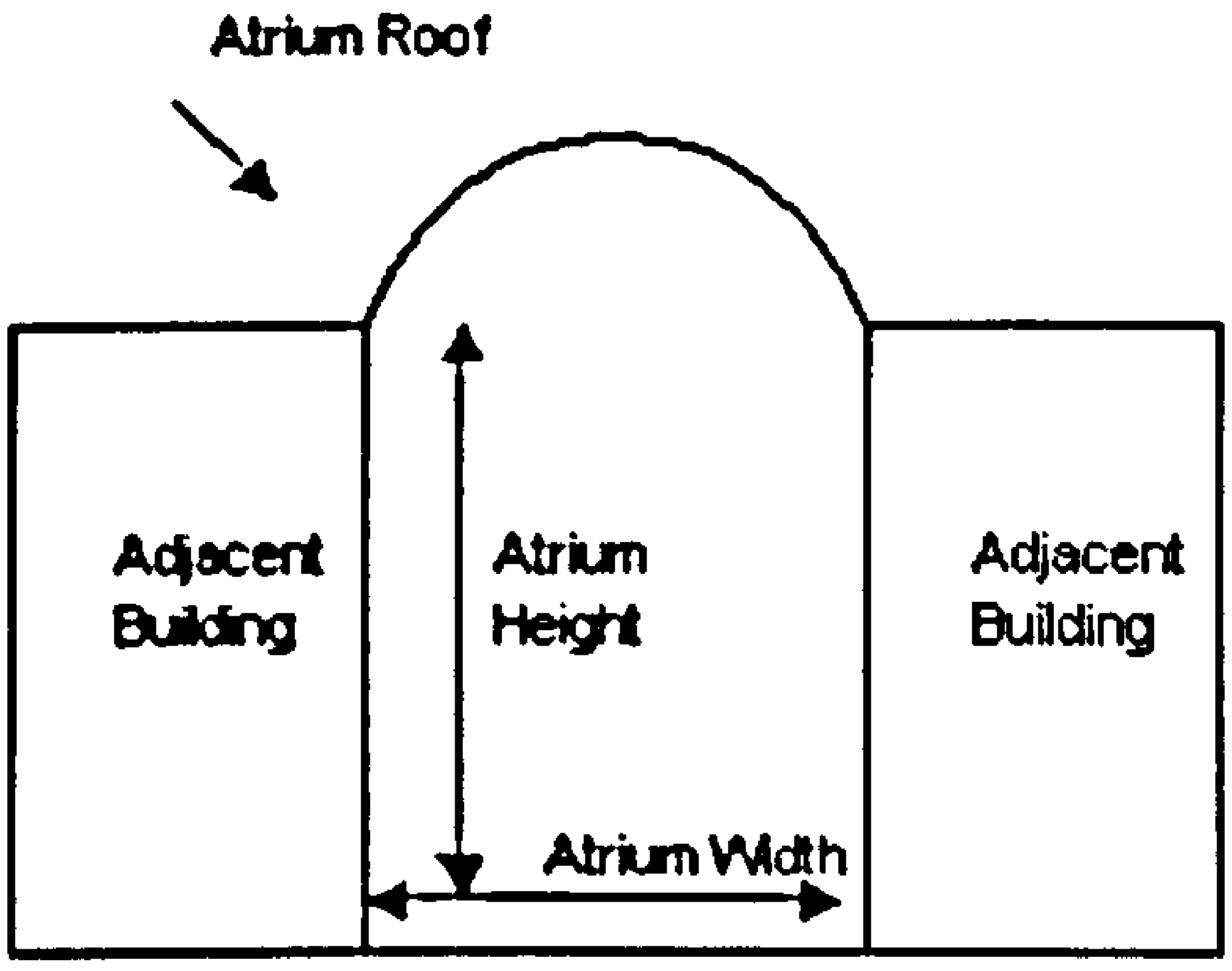


Figure 2. 1:The physical characteristics of the modern atrium building

2.2.2 History of the Development of the Atrium Building

2.2.2.1 Historical Background

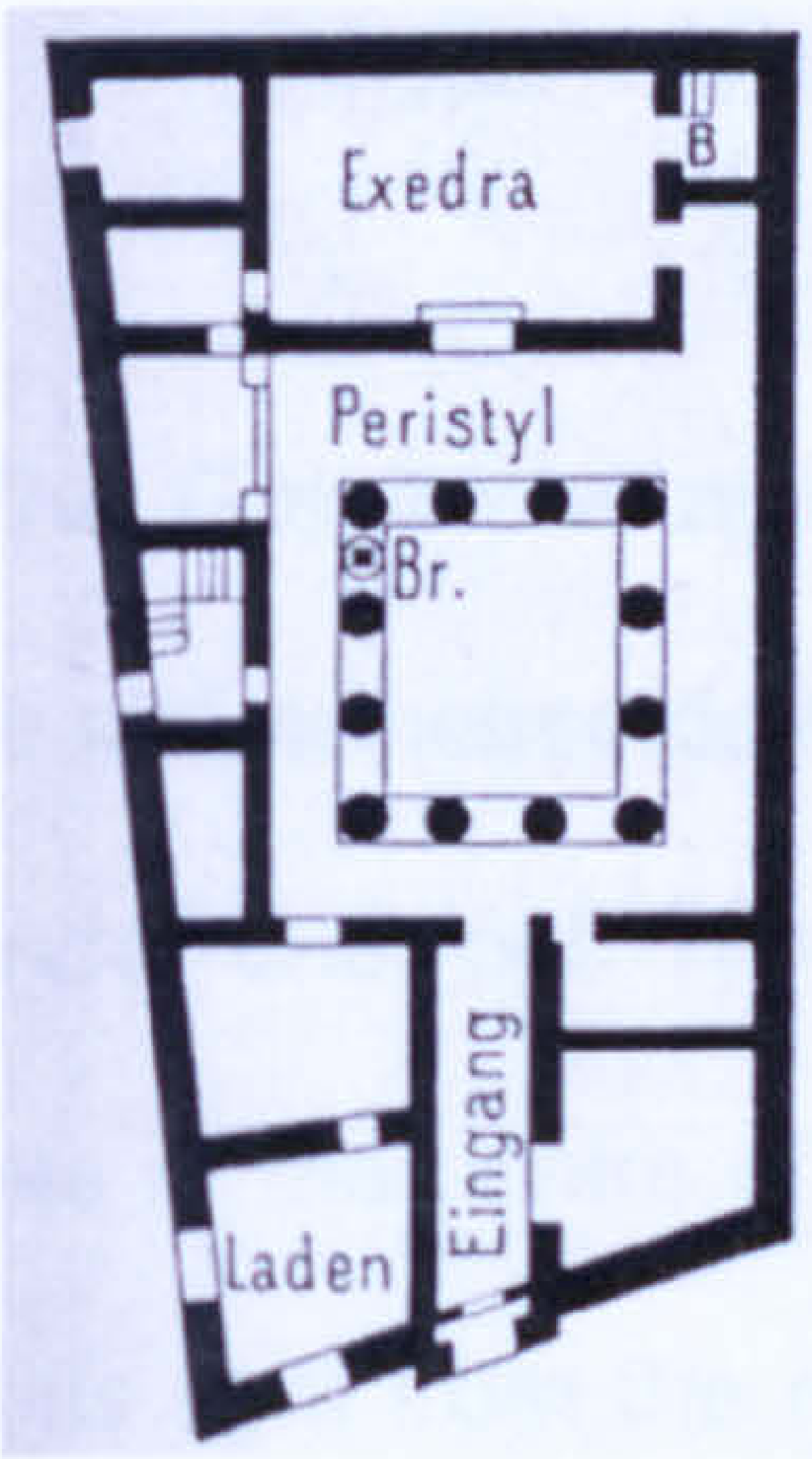
Historically, atria were uncovered internal spaces (courtyards), within dwellings in Southern Europe. They provided a tempered climate and were valued as protected, private spaces.

"Courtyard" usually suggests a part of the house shut in by walls, or at least a partly open room, and throughout history, it has played an important role. This type of the courtyard house was the typical local house in Greece over the centuries.

The courtyard house, sometimes called the **atrium** house or garden-court house (although there are differences), is an early-specialized form, which usually relates to particular regions. However, it evolved all over the world and during every century, and sometimes, having become established, disappeared again.

Originally the word "atrium" meant "black" (focus), because it was there that the hearth was located and the escaping smoke darkened the ceiling. Climate, light, vegetation and topography played an important role. It was not long before it had become the centre of domestic life, particularly because of the surrounding rooms, which sometimes formed a continuum with it through open doors and received their light from the opening in the atrium roof.

Figure 2. 2:The Palace of Knossos, Crete, Greece [Castleden, 1997 #86]



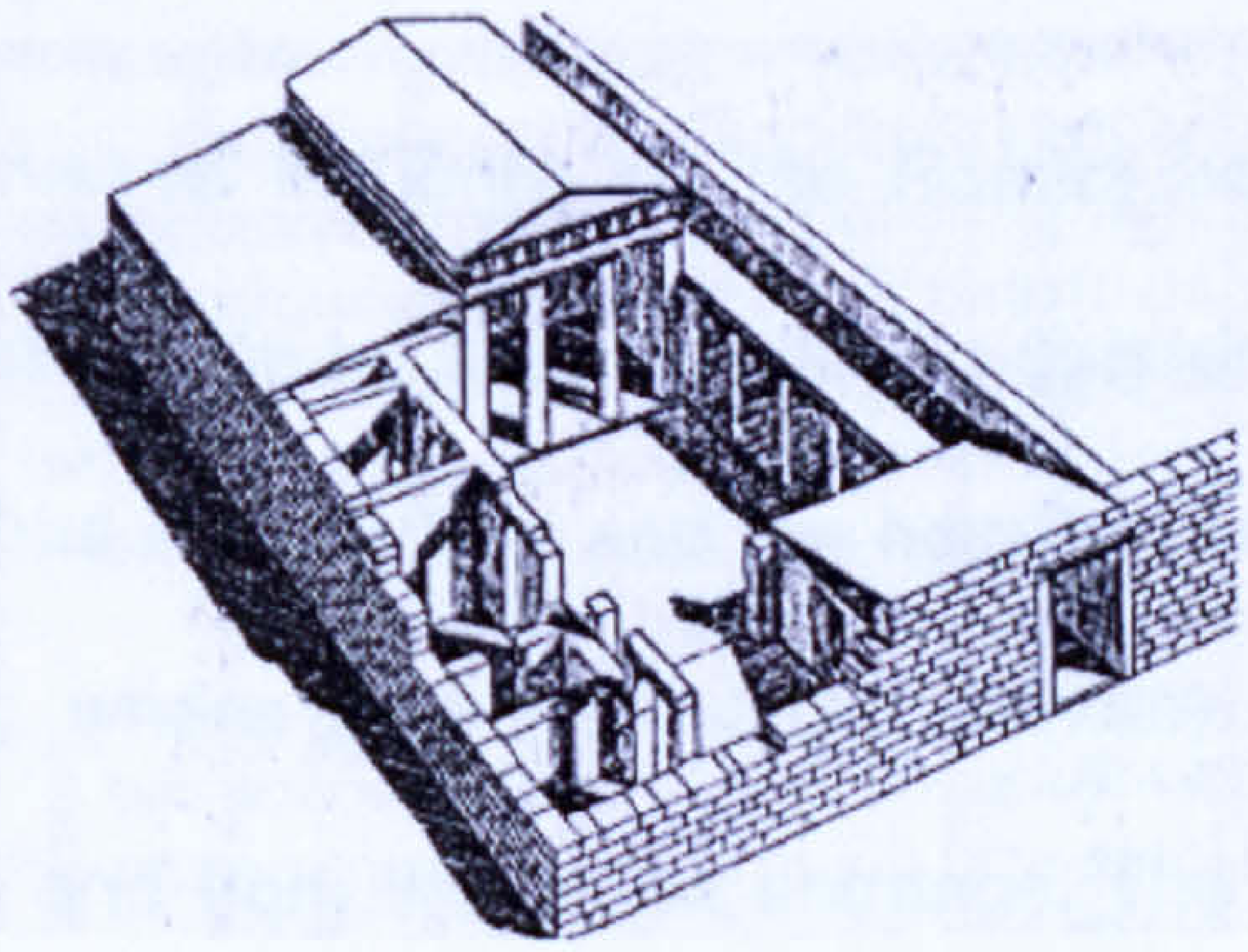


Figure 2. 3: The Greek megaron house with the peristyle in Delos [Bednar, 1986] (left)

Figure 2. 4: The Greek megaron house with the open courtyard in Priene [Bednar, 1986] (right)

In essence, the courtyard house was a town house in the civilizations of Greece and Rome. The courtyards houses at Knossos on Crete (Figure 2.2) date from 2000 BC. The Greek megaron house with a courtyard pillared on only one side was entered directly from the street; the reconstructed examples in Delos (Figure 2.3) and Priene (Figure 2.4) are of this type. Later upper storeys were added. House development reached its apogee during the heyday of Greek civilization in the 4th and 5th centuries BC. The "peristyle house" was therefore the original form of the oriental courtyard house and had grown more sophisticated with time.

Between the fifth and second centuries BC, the Greeks enlarged and developed the courtyard house. The house plan shown from Olynthos near Thessaloniki, a city destroyed in 348 BC, shows a short hall that leads directly from the street to the courtyard, which is surrounded by columns forming a peristyle (Figure 2.5).

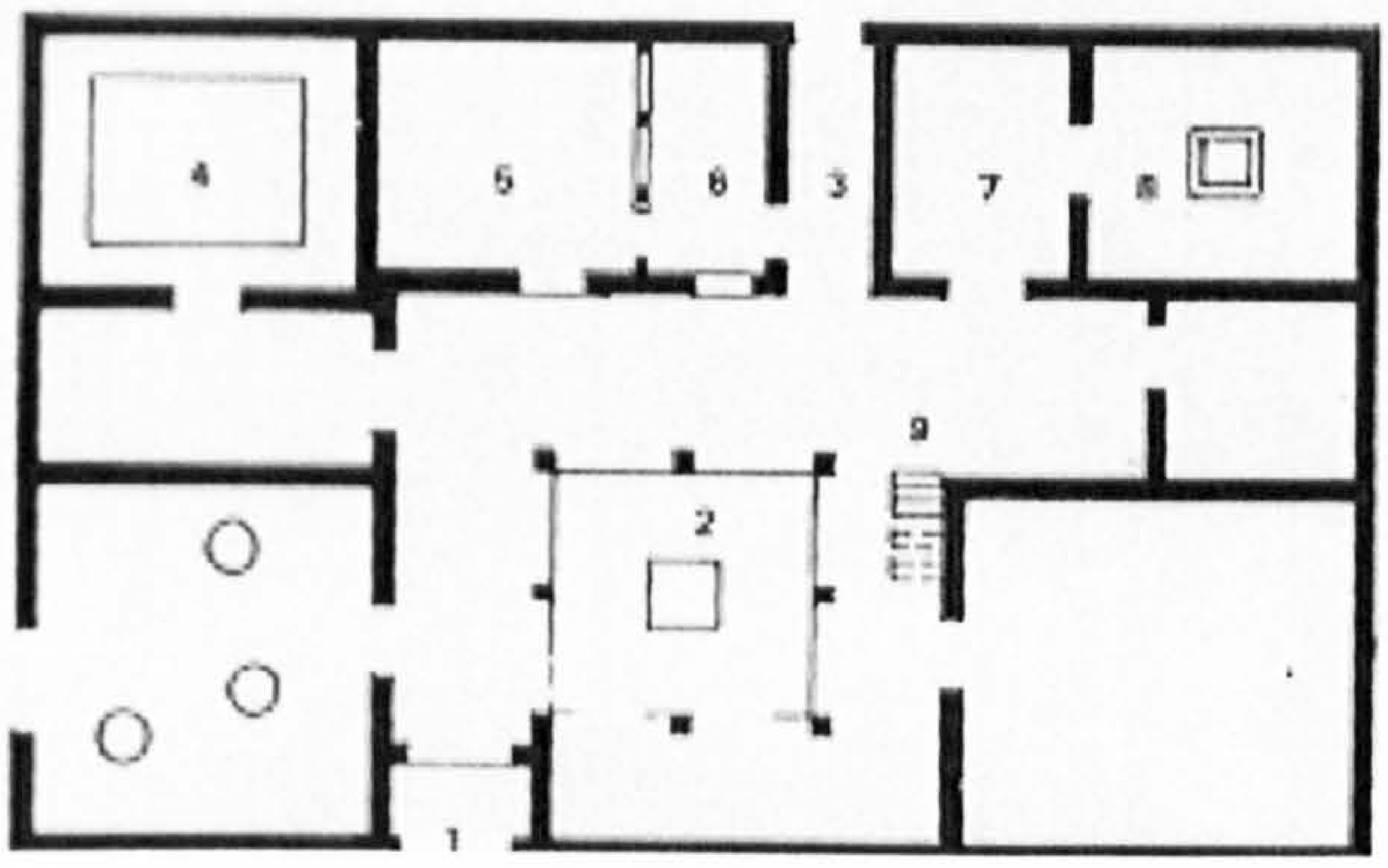


Figure 2. 5 Site plan of the house in Olynthos [Bednar, 1986]

The Greek civilization had a marked influence on the Roman house, which made the atrium house develop as an all-in-one house with its living quarters and utility rooms under one roof. These houses had no windows and the hearth, with its smoke outlet, was at the centre of the building, where there was no roof (atrium). This house received its light from the roof opening and from the house entrance. The atrium was the hall with the open roof, which ultimately assumed the form of a courtyard.

As revealed so far, the concept of an atrium has evolved and changed considerably throughout the course of history. It originated as the primary space of a Greek and later of a Roman house (Figure 2.6), the communal space to which all other rooms were related. The classical concept of the atrium is evident in the houses of Rome, dating from the third century BC in Greece. Atrium courts were seldom really enclosed, but they worked in the Mediterranean climate. It was also a place of arrival and circulation, which brought light and air to the centre of the house through the open roof. In the evolution of this concept, many of these characteristics have been retained and others added, most notably that of an atrium as an enclosed interior space. In fact, it was not until the Industrial Revolution brought iron and glass that anything new could happen.

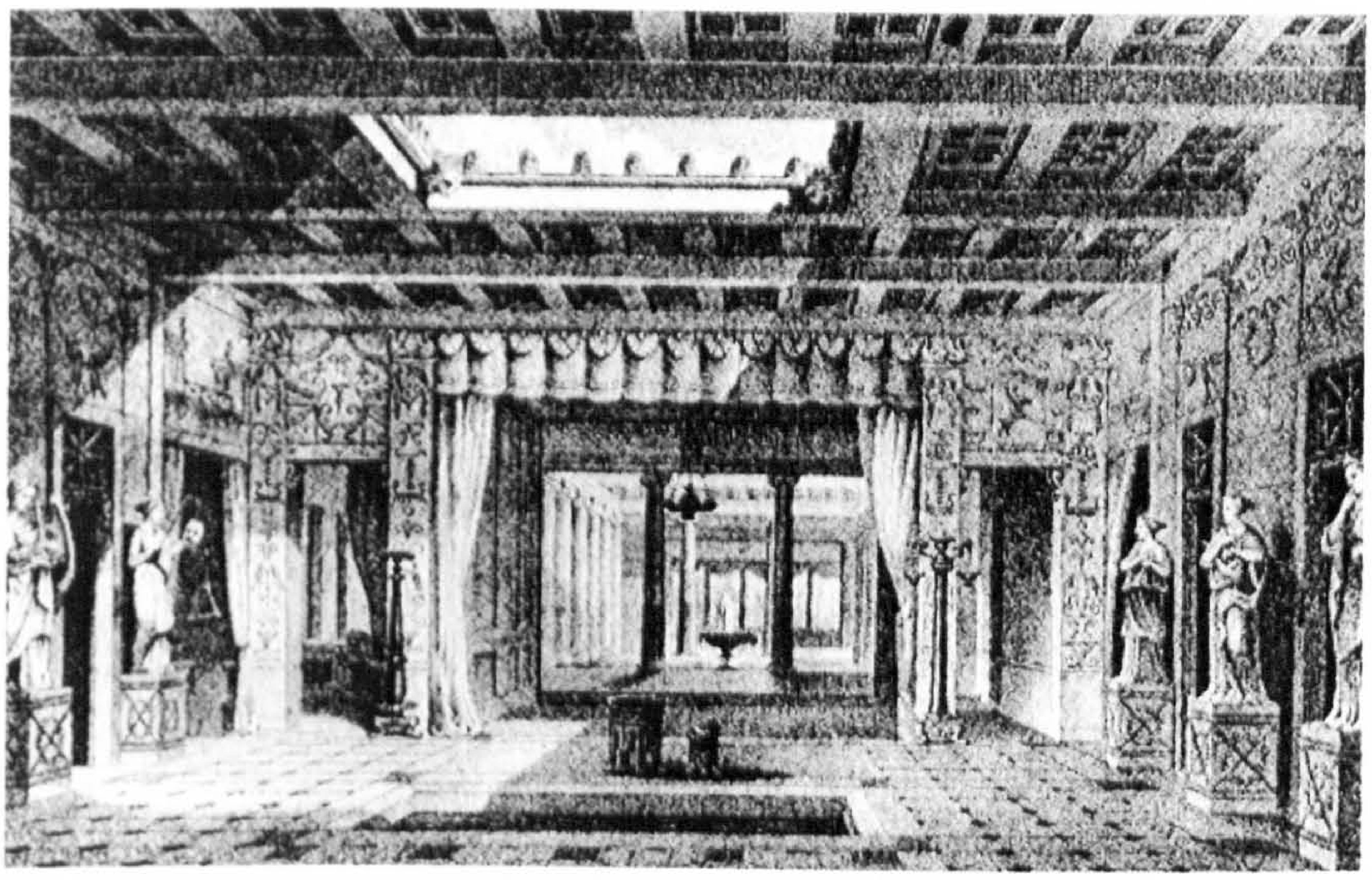


Figure 2. 6: The atrium Roman house (Bednar "The New Atrium")

2.2.2.2 The development of the modern atrium

The first phase in the development of the atrium was as shelter from the sun first in the courtyard of a Greek and a Roman house. In most recent centuries the atrium appears in the form of covered market streets, railway stations, and more recently hotels, hospitals, shopping malls, office buildings, public and private buildings. Following that, it spread through European cities as arcades, or passages, as in Milan's

Galleria, the first of this sort. These were dependent on the technology of steel and glass and served only as shelters from wind and rain.

In the 19th century, the development of iron, and glass technology created a new possibility for courtyards. The development of strong, inexpensive pane of glass allowed the courtyard to be glazed over and transformed into modern atrium, creating an interior space protected from climate but still enjoying the light, and view of the open sky. Perhaps the first of these was constructed for the London Great Exhibition in 1851 (Figure 2.7). The 1950's brought a revival of the atrium as a commercial amenity in offices, shopping malls and hotels, initially in North America and then in Europe. Nevertheless, it was not until the 1970s that an enormous boom in atrium construction took place (Bednar, 1986), (Saxon, 1983). The new atrium was born, and began to develop as a unique building form with a wide range of design possibilities (Bednar, 1986).

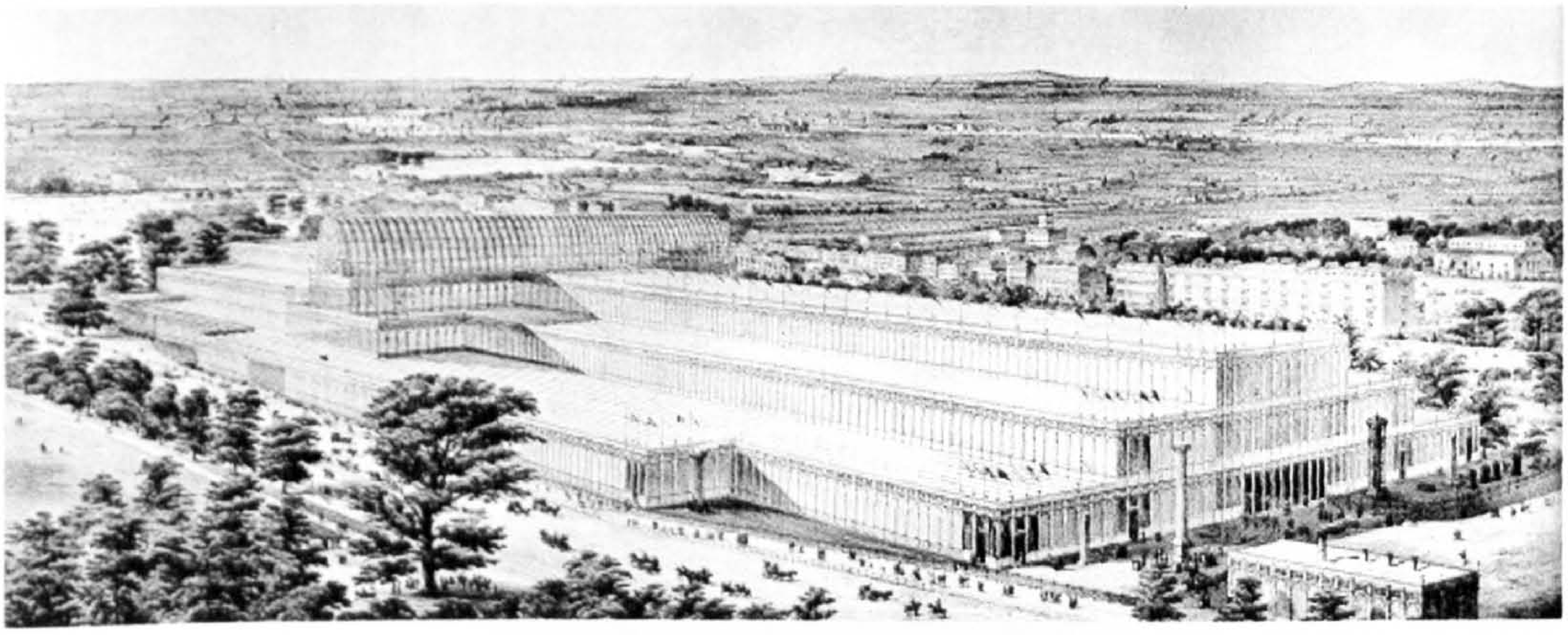


Figure 2. 7: The Crystal Palace, [Frampton, 1983]

Several thousand buildings containing atria have been completed worldwide since the feature was reintroduced into the Hyatt Regency Hotel, in Atlanta in 1967 (Figure 2.8). The shopping malls of Victor Gruen, the hotels of John Portman, and the office buildings of Roche Dinkeloo (Figure 2.9) were followed by exuberant new and remodelled exemplars by I.M.Pei Helmut Jahn, S.O.M, Philip Johnson, Cesar Pelli (Figure 2.10), and Eberhard Zeidler. Mainstream commercial development in Canada and the USA adopted the atrium and galleria concepts universally and proved their economic value and their technical feasibility.

Atriums in today's sophisticated society attempt to tie together complex functions within the city. However, the origin of the atrium as an enclosed place filled with natural light has not been denied in its development.

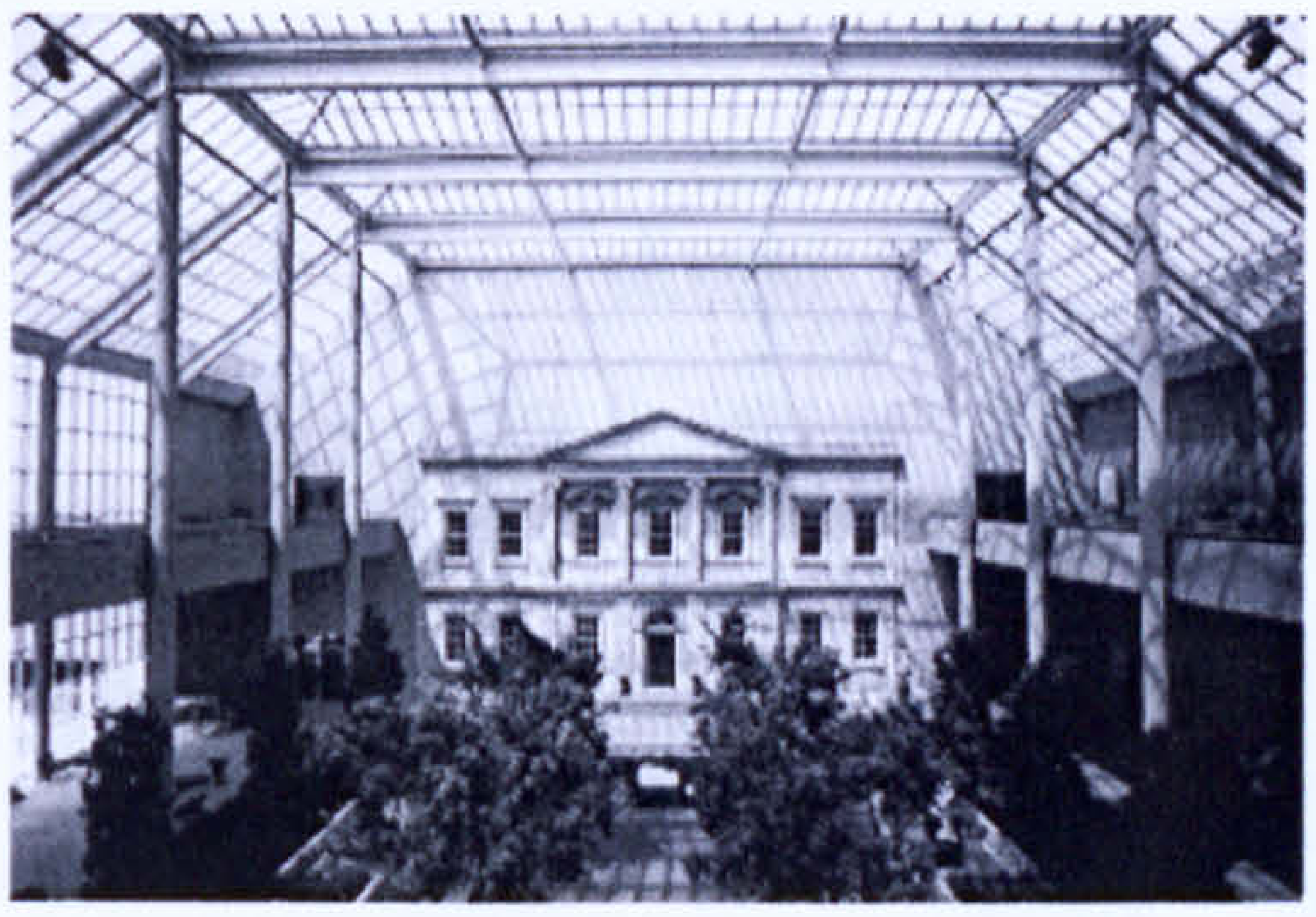


Figure 2. 8: The Hyatt Regency Hotel, Atlanta, 1967: The hotel whose covered central court was first called an atrium [Saxon, 1983] (left)

Figure 2. 9:Metropolitan Museum, NY, 1980 Roche & Dinkeloo. This is one of the several uses of the atrium at the museum and connects extensions whilst retaining old facades, [Bednar, 1986] (right)

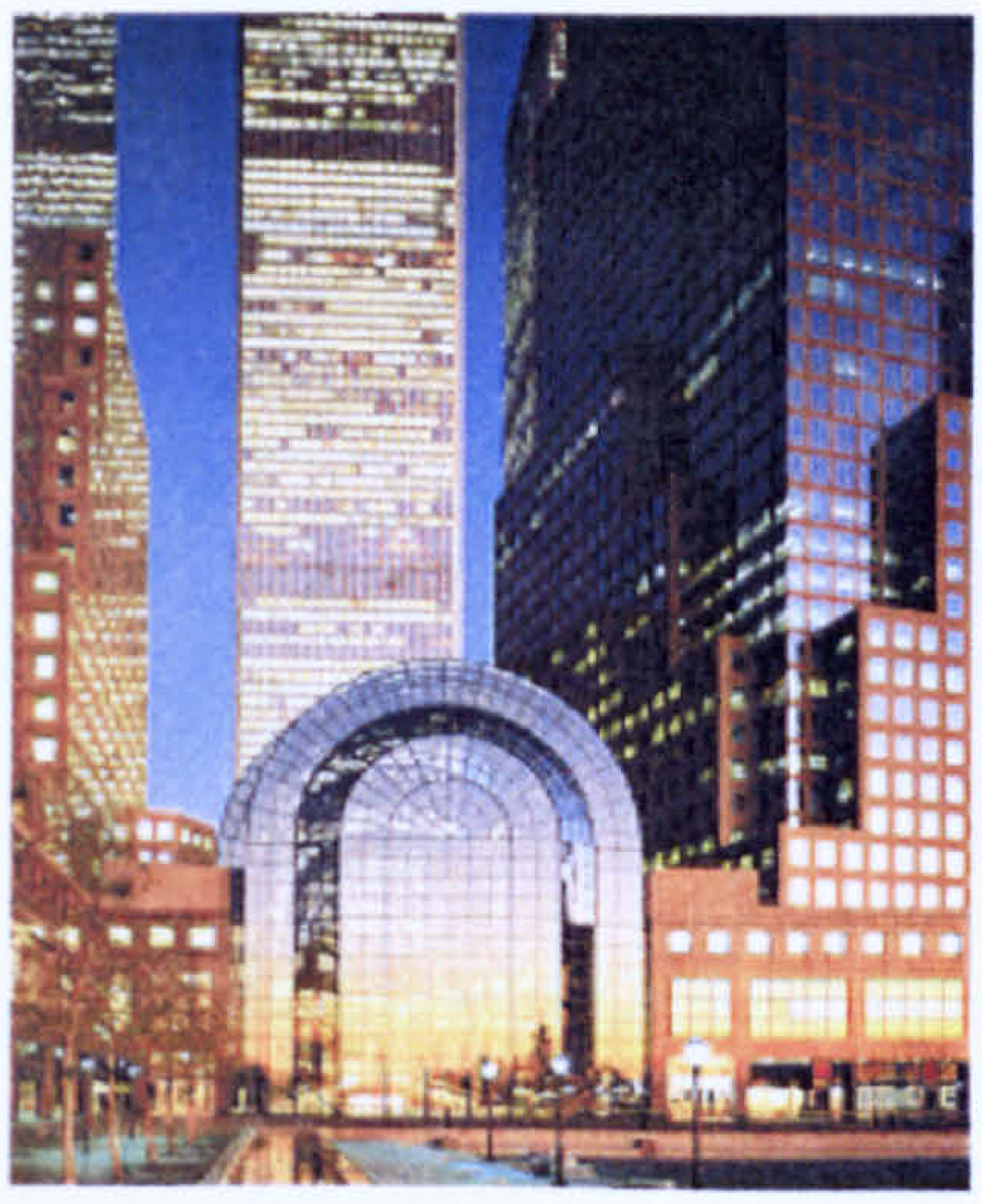


Figure 2. 10:The winter garden, World Financial Centre, N.Y.C Pelli [Saxon, 1994]

2.2.3 Generic Forms of Atria

In an effort to define the contemporary concept of atrium, Bednar (1986) has analysed its recent development with a view toward the historical evolution of the form in which the salient characteristic is spatial and leads to a new definition of the term: *"Atrium, a centroidal, interior, daylit space, which organizes a building".*

Centroidal is a key word in this definition; in fact if a space is in the centre of a plan and extends vertically through the building in section, then it has the potential to spatially organize that building.

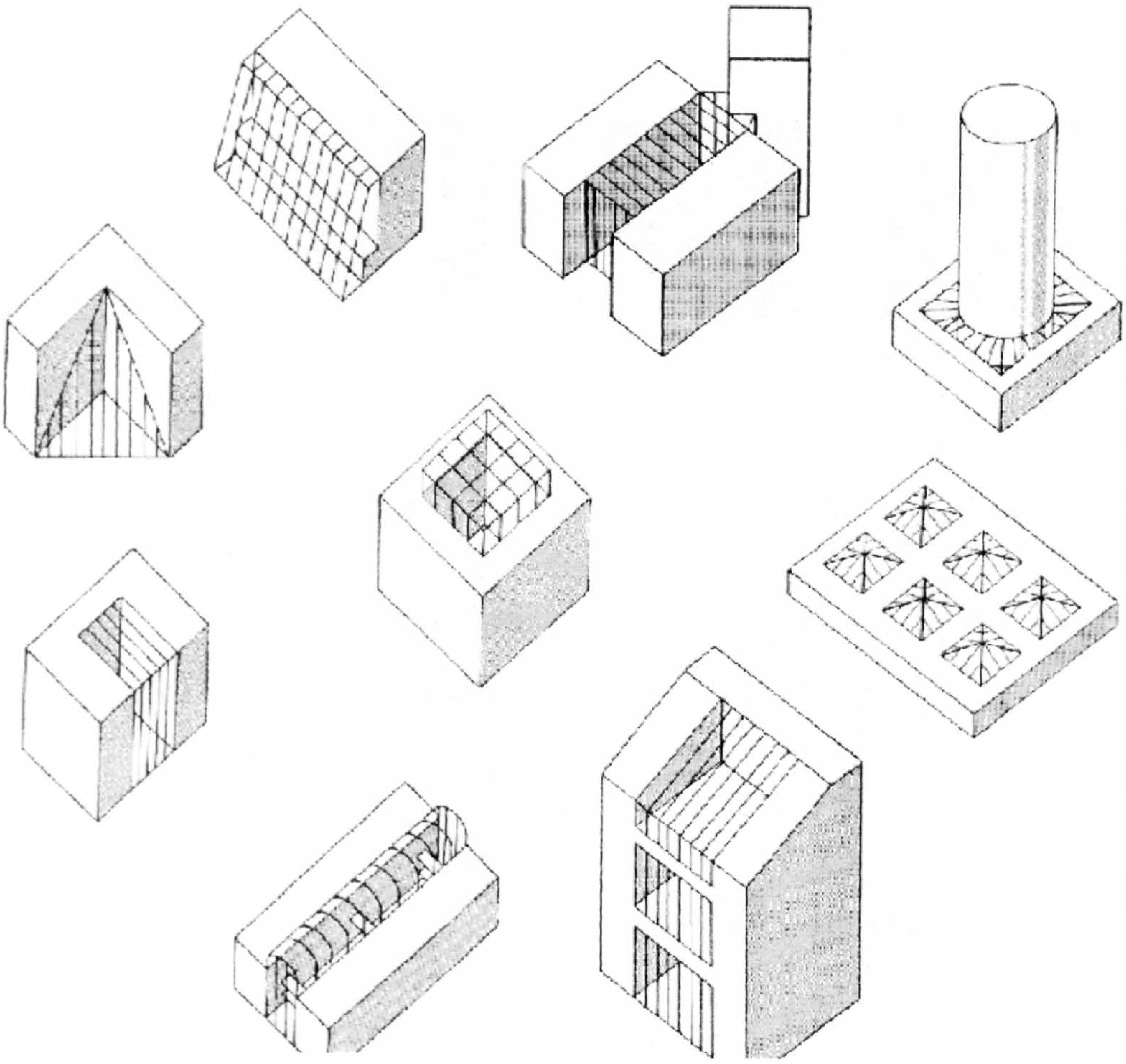


Figure 2. 11: A taxonomy of atrium building types from Saxon,[Saxon, 1983]

There are a variety of forms, which an atrium building can take. In this research there are four main types as shown in Figure 2.12 and they are:

a. Closed Atrium: This type is defined on all sides by occupied zones and the only source of daylight and view is from the roof.

b. Open-Sided Atrium: It can have one, two or three sides partially or completely glazed. The roof may or may not be glazed.

c. Linear Atrium: The occupied zones are on opposite sides of the atrium and the circulation zones across. The roof is the main source of view and daylighting although the ends of the atrium maybe glazed as well.

d. Attached Atrium: It spatially organizes part of the building and the roof maybe glazed as well.

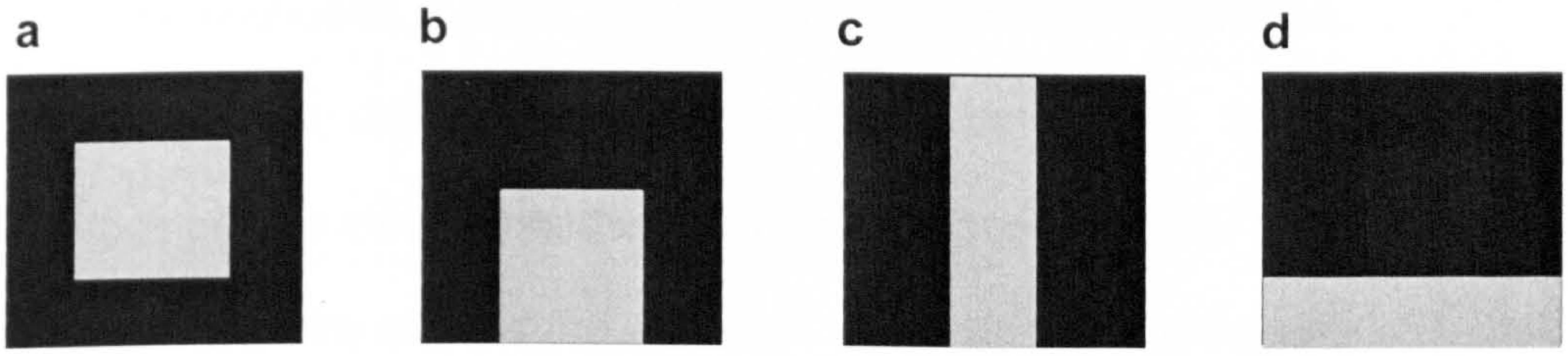


Figure 2. 12: The four generic forms of atrium buildings used in this research

The pure forms, one-, two-, three-, four-sided and linear atria can be applied to small, single buildings as well as to large complexes. The complex forms are more appropriate to higher density, larger-scale developments.

These main types will be used in this research during the process of the parametric study.

2.2.4 Functions of Atrium

The question of the re-emergence of the atrium building has been debated by many researchers (Bednar, 1986), (Ikezawa, 1986). In order to explore the possible reasons for that, one should probably look into the very specific qualities that make atrium buildings so attractive to designers and users.

A review of historical examples and modern case studies suggests that atria serve many functions in a variety of building types. In fact, the atrium concept has wide-ranging advantages over conventional modern building forms. An atrium can organize a building functionally by accommodating a purpose shared by all occupants, serving as a lounge, reception or exhibition area. Furthermore, in some buildings it serves as a social, institutional or symbolic organizer. In others, atria serve to channel, modify and distribute daylight and the natural flow of energy. Bill Hillier (1984) identifies that atrium buildings exist for four reasons, which he called the four functions of architecture: economic, cultural, shelter, and accommodation function.

All of the atrium functions described below are interlinked and these advantages are the motive why they became very popular public spaces. Scale, design flexibility and use are some of the important features for the designer.

2.2.4.1 Economic Function

Atrium buildings can provide a view from adjoining spaces and that can be a major force in some commercial developments where rental values may be considerably higher for rooms with a view (Bednar, 1986). Many atrium buildings appear expensive and are successful because of their extra attraction and earning power (Figure 2.13). Shops and offices built around atria have the potential to let quickly for premium rents. Atrium buildings are also capable of providing 'shallow' space for perimeter offices rather than the deep spaces of a tower or low-rise, block-covering building.

Atrium design can allow more successful recycling of existing buildings like in the case of courtyards. Over deep spaces can be hollowed out to more useful depths. To that direction, many argue that atrium buildings can run for less than conventional buildings due to lighting and consequently to cooling energy savings.

Figure 2. 13: The atrium as an economic machine: Bateson Building by Sim van der Rynat in Sacramento, California, 1977.

2.2.4.2 Cultural Function

Atrium buildings can fulfil an architectural role in unifying a large building by providing a focal point. The presence of a large "open" space within a building can create a unique social environment by serving as a place to gather, connect or divide different parts of the same building or as a place for occupants to look into. Vertical and horizontal communication can be greatly improved by linking different parts of a building with an atrium, which can give them a shared sense of identity (Figure 2.14).

Atria appeal to the mind and the senses. In fact, they put people to the centre in a way lost in recent architecture. Furthermore, they encourage play: people watching and promenading, moving through space, enjoying nature and social life. They provide a visual antidote to the oppressive interiors and the formless external spaces of today.

However, atrium buildings are far from being retreats from the city; they contribute to it by restoring its character: the street-line, fragmented by modern development, can be regained; the plaza, usually an uncomfortable desolate tract, can be made welcoming.

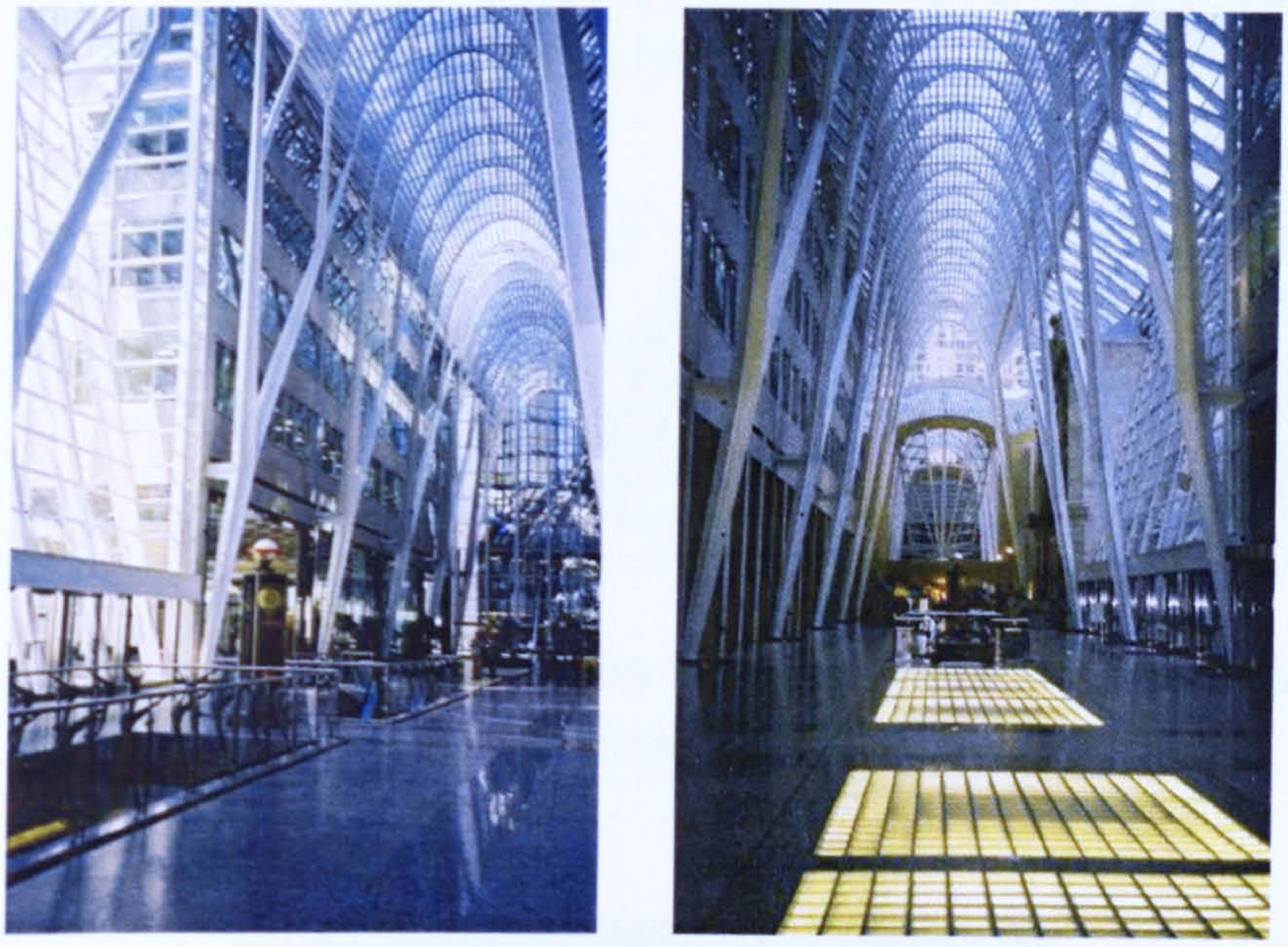


Figure 2. 14: The atrium as a cultural symbol, Santiago Calatrava's Lambert Galleria, Toronto

2.2.4.3 Shelter Function

The question of shelter is central to atrium buildings (Figure 2.15). The sheltered central court is a great amenity in itself, creating a type of space not otherwise available in most cities-an all-weather public gathering space. It acts as a buffer space, a transition area between inside and outside. It is in the interaction between the court and the space around that this refined protection goes on. The central court of an atrium creates an all-weather semi-public gathering space. The atrium can bring light but keep wind, rain, solar gain and extreme temperatures away from overlooking space, increasing comfort. Furthermore, the shelter effect is most marked when the atrium is not serviced to reach full-comfort conditions itself, but acts as a buffer space, a transition area between inside and outside.

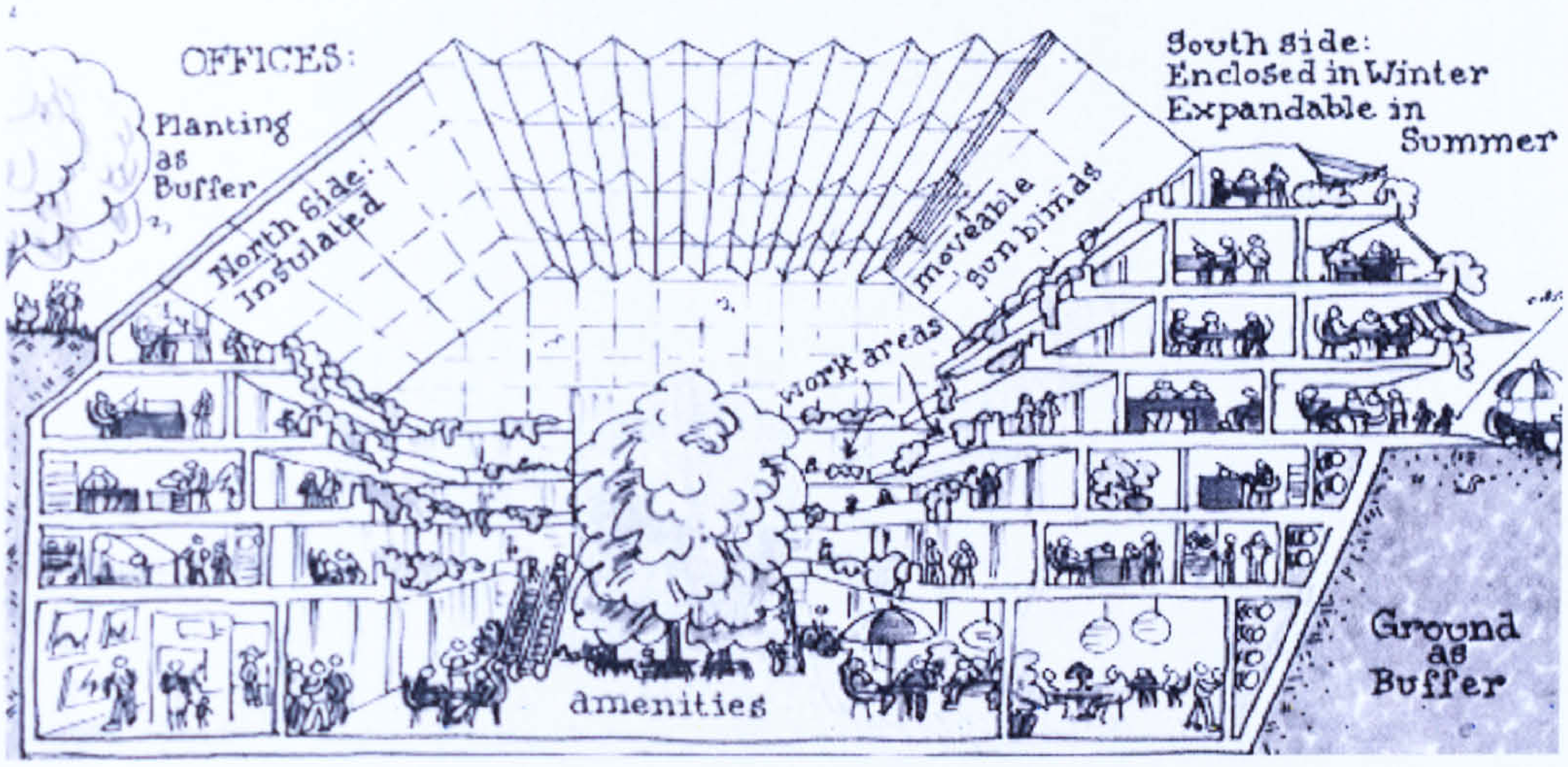


Figure 2. 15: The sheltering atrium from Terry Farrell & Ralph Lebens' thesis, "Buffer thinking" [Saxon, 1983]

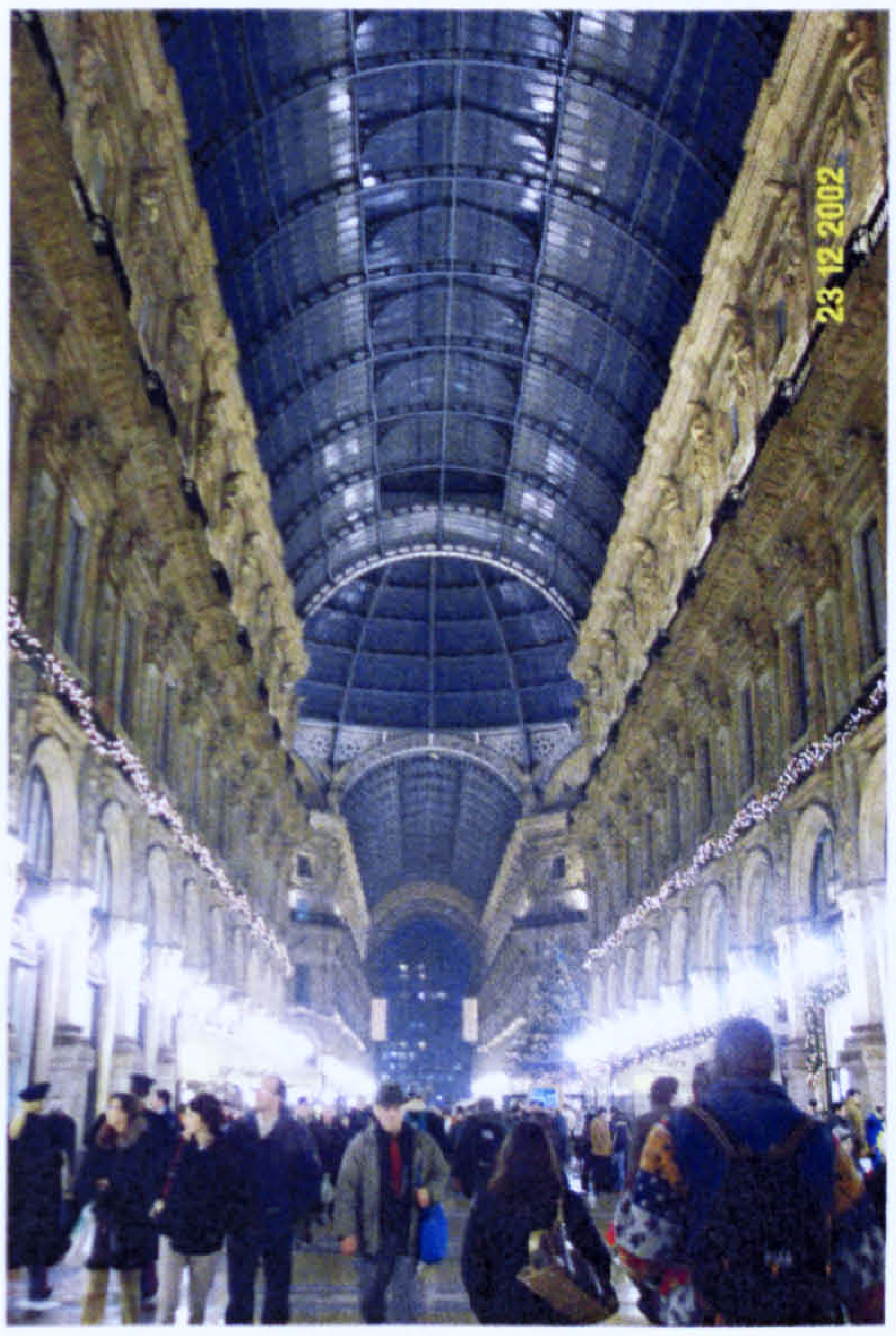


Figure 2. 16: The Galleria Emmanuel II in Milan

Vertical and horizontal communication can be greatly improved by linking disparate parts of a building with an atrium. Similarly, hospitals, schools, universities, libraries, museums, shopping centres, hotels and multifamily housing can enjoy the benefits of atria. The Galleria Emmanuel II in Milan is one of the most famous examples of a glazed space used to link streets, by the form of an arcade (Figure 2.16).

2.2.4.4 Accommodation Functions

The need for accommodation is usually the force, which triggers the building process. The atrium itself can provide useful space (Figure 2.17). Apart from constituting a lobby and circulation space with access to all parts of the building, its floor can be a restaurant, lounge, exhibition or performance space, or a market area. The views and accessibility it creates can enable upper levels to work as an extension of the 'ground' level.

Figure 2. 17: The accommodating atrium: Central Beheer Offices, Apeldoorn, Holland (Saxon, 1983)

2.3 Atria and Energy

Even if the atrium has become popular, its environmental aim is generally unclear and its role has been questioned (Watson, 1982) "*Is it a large top-lit multi-*

storey room in the centre of a deep plan building? Is it artificially lit and air-conditioned with lavish furnishings and exotic plans? Or should it be regarded as a free running intermediate space, with an environment lying somewhere between the world outside and that of the closely controlled indoors".

Apart from the aesthetic, social, economic, shelter and accommodation functions, one of the atrium's most important features lies in its potential to modify the physical environment within the atrium well and the spaces adjacent; atria are primarily intermediate spaces, and the atrium environment lies somewhere between the outside climate and the more controlled internal environment. Many argue (Watson, 1982), (Baker, 1988), (Lehrman, 1984) that through this function the atrium has the potential to reduce energy loads associated with heating, cooling and artificial lighting. Though, it is possible to result in an increase in energy consumption of the building if the design is poor.

Traditionally, the indoor climate in the ancient courtyards was maintained throughout the year by passive means (solar heating, natural cooling). Since the developments in air-conditioning and the increased use of glass on building facades, passive atria, conservatories and arcades became less common. The primary role of the modern atrium, as considered by most contemporary architects, is to enhance the aesthetic and visual quality of the building. This new role however, differs from the ancient one that was primarily environmental. In recent years the energy-saving potential of atria relying on passive solar principles has been rediscovered.

Atrium buildings offer several lessons upon which to base new energy design concepts: first, human comfort is achieved with natural climatic means by architectural devices that create gradual transition from the outside to the building interior; second, if designed properly, protected spaces and buffer zones create free energy by reducing or even eliminating the need to heat, cool or light building interiors by costly mechanical means (Watson, 1982).

Figure 2.18 shows the environmental functions of atria evolved from open space as identified by Baker (1988).

Certain features are responsible for the microclimate that is created in an atrium such as particular glazing orientations, wind exposures and shading devices. Proper selection of glazing types, shading devices, fenestration orientation and geometry, together with overall atrium size and shape will determine the overall energy costs and benefits for a specific building in a given climate zone. A study by Hastings and Ruberg (1980) of the effects of placing glass canopies across existing streets, found that the street canopy cut adjacent building heat-losses by 57%.

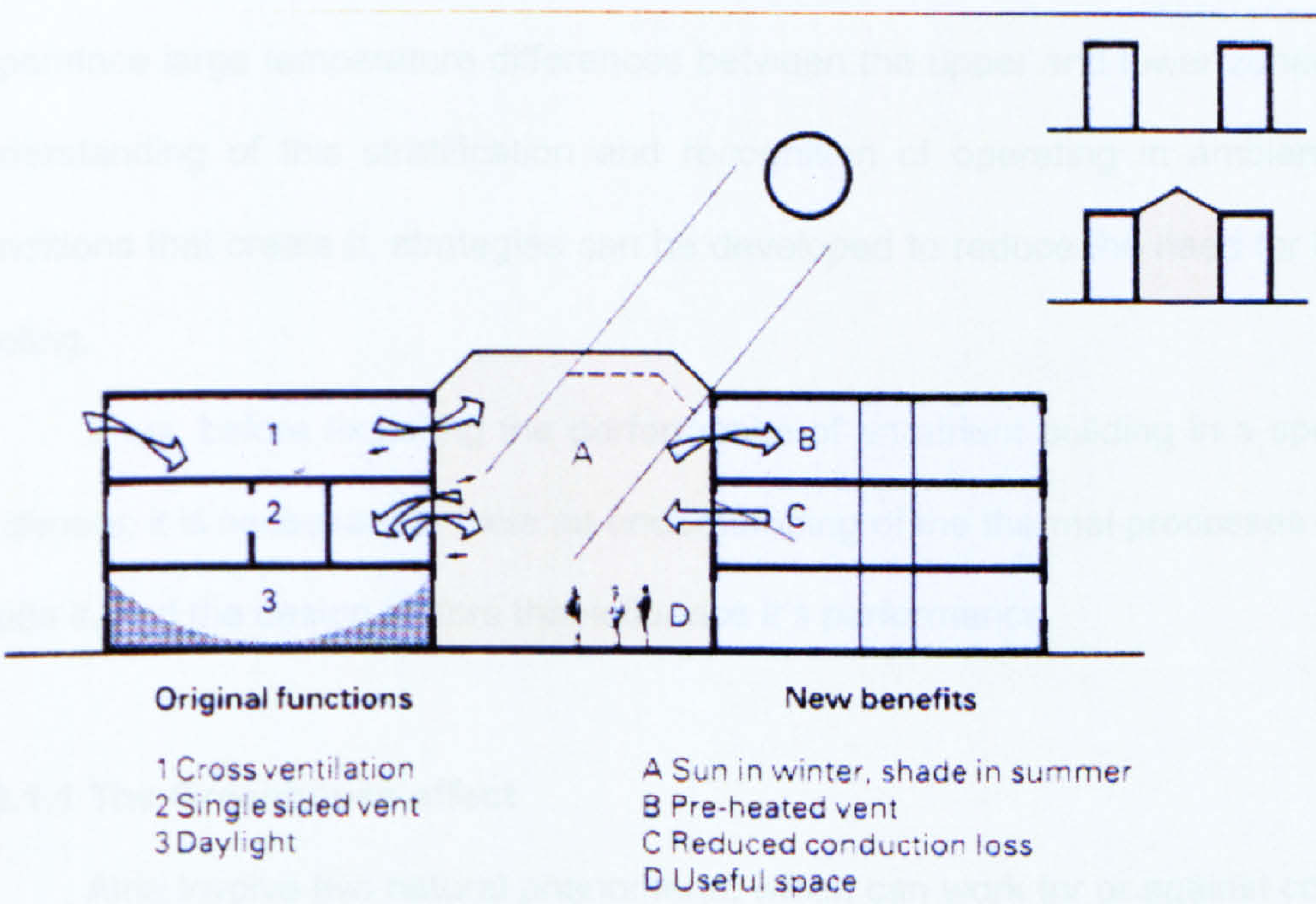


Figure 2. 18: The environmental functions of atria evolved from open space [Baker, 1988]

Another important issue, of particular interest to this research, is the quality of comfort enjoyed in the built environment and the potential of reducing its cost. Atrium buildings, by playing a key role as an intermediate space, have the potential of providing more comfort than an outdoor space, however, its energy demands depend on its use and requirements. Conclusively, the successful design of an atrium is a fine balance between the requirements of day lighting, heating, cooling, ventilation, as well as taking into consideration aesthetic and functional issues.

2.3.1 Thermal Processes in Atrium Buildings

As it has been shown so far in this chapter, the atrium has emerged as a popular design element for architects. This might be due to the visual dynamics of these spaces with their multi-storey proportions and utilization of daylight. While atria do have advantages, they often create operational liabilities with high costs for heating and cooling. This is partly due to the architect and engineer's lack of recognition for the thermal processes that take place in these spaces. For example, atria typically will experience large temperature differences between the upper and lower zones. With an understanding of this stratification and recognition of operating in ambient weather conditions that create it, strategies can be developed to reduce the need for heating or cooling.

Thus, before exploring the performance of an atrium building in a specific type of climate, it is necessary to have an understanding of the thermal processes that occur inside it, and the design factors that influence it's performance.

2.3.1.1 The Greenhouse effect

Atria involve two natural phenomena, which can work for or against comfort: the **greenhouse** and **stack effects.**

Glass has the special characteristic of transmitting nearly all solar radiation that it intercepts (which moves through it) and is less transparent to most thermal radiation. Solar energy passes through the windows is absorbed by interior materials, and reradiated into the interior space in the form of thermal energy (heat) which is unable to pass back through the glass to the outside. This has become known as the greenhouse effect (Figure 2.19).

In passive solar architecture, the greenhouse effect can have positive winter results and negative summer ones. In the case of atrium buildings in a Mediterranean climate, there is potential contribution from the solar gains to the heating of the atrium space as well as the heating of the adjacent buildings. However, the same effect can have the reverse results during summer, where excessive amount of trapped solar radiation can lead to overheating. The efficiency of this effect depends on glazing characteristics such as the proportion of glazed area and the spectral transmission curve. It also depends on the surfaces hit by radiation i.e. the absorption and re-radiation characteristics.

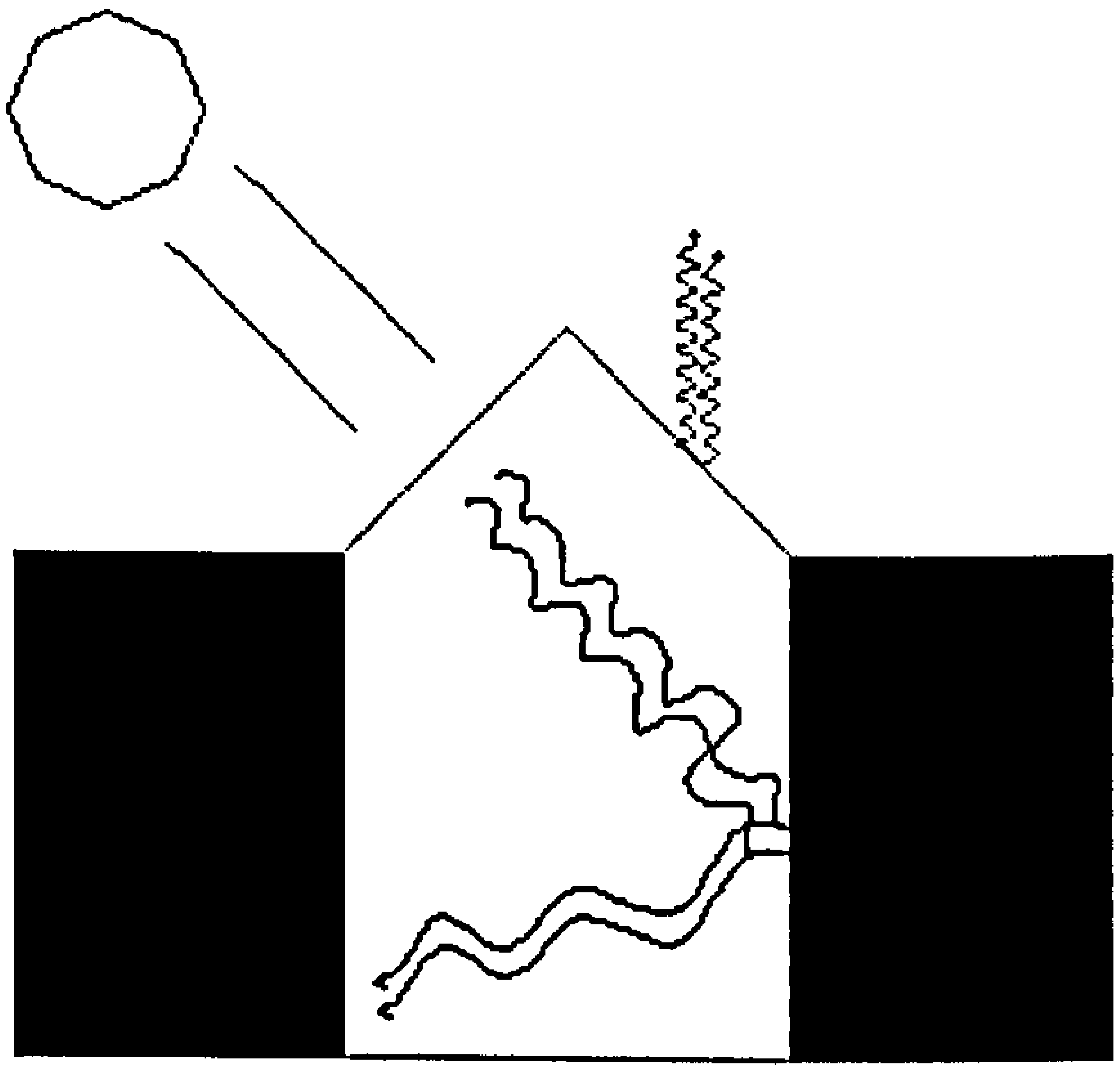


Figure 2. 19: The greenhouse effect: The build-up of heat in an interior space caused by energy input through a transparent membrane such as glass

2.3.1.2 The Stack effect

The **stack effect** is a physical property of airflow in a vertical space vented at top and bottom. It occurs when cool air at the bottom is warmed. The warm air rises and if it escapes it can be replaced by air being drawn in at the bottom. Buoyancy forces can also work in reverse. This effect can be used to naturally ventilate a building (Figure 2.20). Wind movement over the higher openings will enhance the suction effect. Combined with the buoyancy of air warmed by the greenhouse effect there will be strong upward draught.

When this effect is applied to the building, the temperature gradient effect can be used to expel the warm air from the building naturally where the air inside a building is warmer than ambient air. If the openings are provided at the top and bottom of the building, the warm air rises naturally and escapes from the top outlet while cooled fresh air will enter through the opening at the bottom.

Stack effect can be put to effective use to release unwanted heat from a parent building through the atrium. In the atrium space the temperature at the top can be much higher than that at the bottom and the effective openings promote the natural ventilation due to the stack effect.

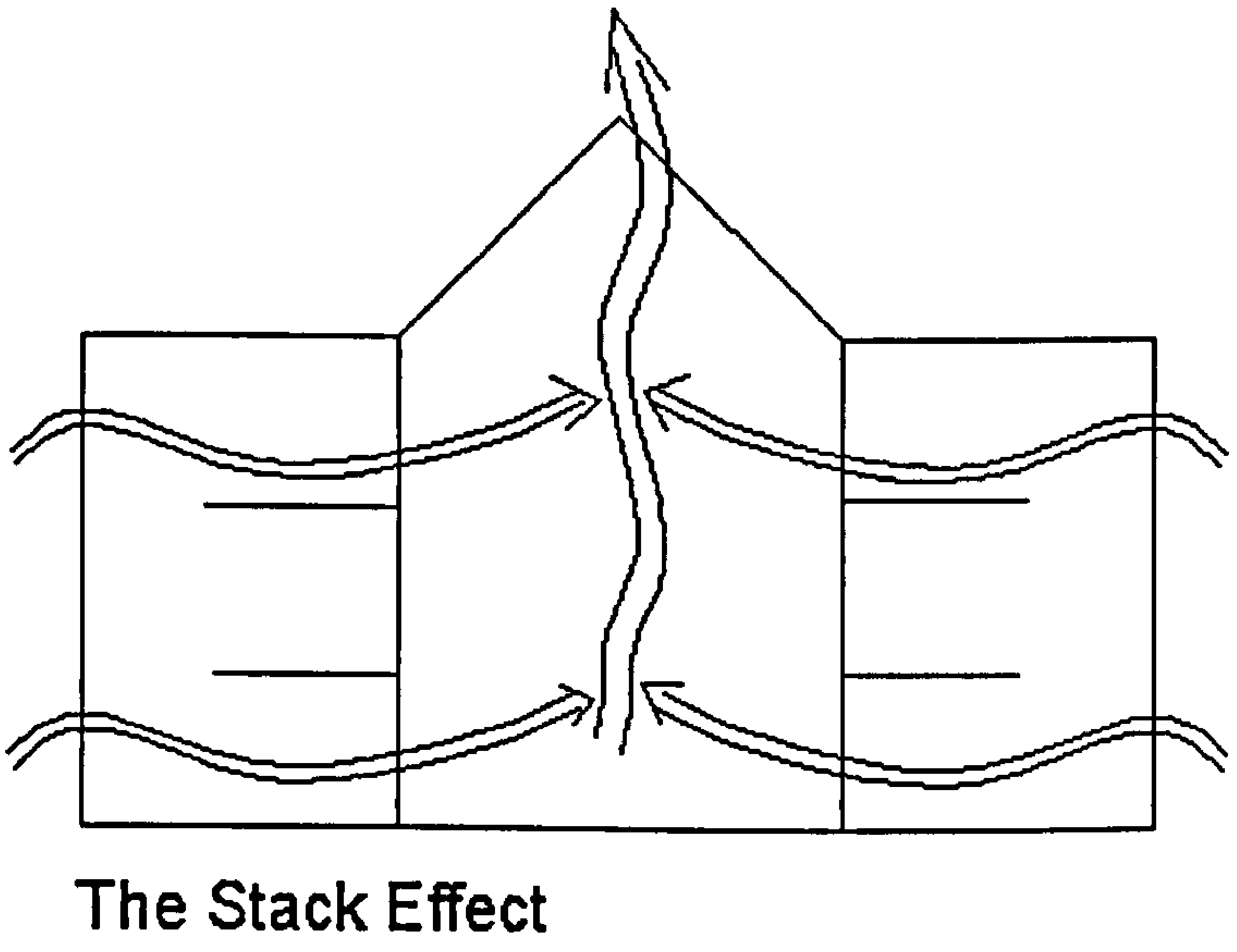


Figure 2. 20: Hot air rises and escapes through small gaps in the building fabric at the top of the building, drawing in new cold air through similar gaps at the bottom.

Working with these two effects make climate-control relatively simple; working against them can be costly or even impracticable. The green house effect can be the cause of discomfort in an atrium building in a warm climate due to overheating. Climate control techniques include proper selection of glass (reflective, etc.) and adequate shading, topics that will be discussed in the next paragraph.

Like many other environmental principles, the stack effect can either be a problem or an opportunity. It is the main motor generating draughts and often the largest single cause of heat loss. However, when carefully controlled it can produce an effective level of natural ventilation. If respected and built into the building design, the stack effect is by far the most effective way of keeping an atrium ventilated in summer.

2.3.2 Energy Potential

An atrium designed as an unconditioned space has the potential of requiring no other energy than that available in its position as a buffer zone between the outside and indoor environments. There are increasing number of examples to illustrate that energy-efficient atrium designs can affect the overall thermal energy balance of buildings in many ways such as reducing heat losses, solar gain properties, and can offer excellent means for natural ventilation and breezeways. How the atrium can work as an energy-efficient modifier of climate is best discussed by examining separately its potential for natural heating, cooling and lighting. Each of these factors is affected by climate and building type.

2.3.2.1 Solar Heating

Most atria will function as direct-gain spaces, retaining heat due to the greenhouse effect described previously. If an atrium can be used as an unconditioned circulation space may not require any additional heating. Additional tempering can be gained from surrounding occupied spaces, depending upon the thermal separation between them and the atrium.

Watson (Watson, 1982) has prioritised the following design principles for an atrium's heating efficiency:

1. Maximize winter solar heat gain by proper aperture orientation
2. Proper placement of interior building material for heat storage
3. Prevent excessive night-time heat loss with appropriate insulation system for the glazing
4. Recover heat from the top of the atrium for use within the atrium space or the adjacent rooms.

The strategies for reducing heating energy consumed in the atrium building vary considerably. All atria act as buffers for their adjacent spaces, reducing their heat loss. The energy savings in the adjacent spaces partially offset the atrium heating requirements. Some atria also reduce total building heating requirements. They act as buffers during the coldest parts of the heating season and contribute heat to adjacent spaces during the milder parts, when more solar energy is available (Figure 2.21).

In the northern hemisphere, glazing orientation on the south façade is ideal, for it allows low-angled winter rays to penetrate. Walls and floors can be used to store heat. Then the stored heat can be distributed to the living spaces around the atrium or the atrium well. Conserving the heat gain is one final consideration: the exterior enclosure is the primary concern, since it usually has a high percentage of glazing. A wide variety of glazing materials with low-emissivity (passage of radiant heat energy) but high transmittance (passage of visual light) could assure better energy efficiency.

The problems of overheating in the summer, especially in the context of the Mediterranean climate, will be discussed later in the chapter.

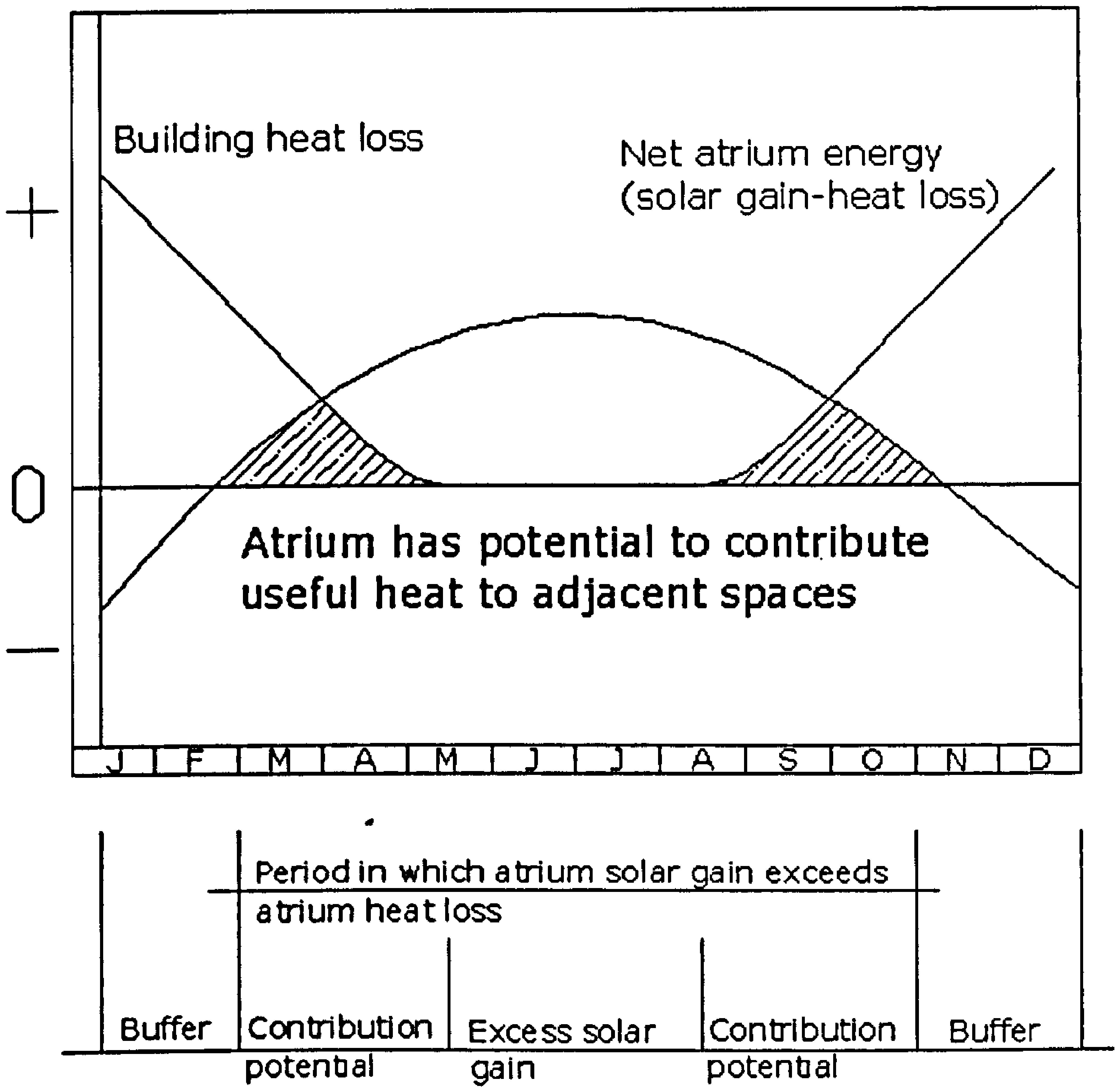


Figure 2. 21: The potential of atrium to contribute useful heat to adjacent spaces

2.3.2.2 Passive Cooling

There are potentially four passive cooling techniques available for use in atrium buildings (Bednar, 1986):

1. Control of solar heat gain (shading)
2. Radiative Cooling
3. Convective cooling
4. Use of thermal mass

In order to minimize solar gain, the need is to provide shade from the summer sun. While there is an apparent conflict between the heating design principle to maximize solar gain and the cooling design principle to minimize it, the sun does cooperate by its change in solar altitude with respect to the building (Watson, 1982). In climates, which have both heating and cooling seasons, horizontal sunshades on southern orientations can keep out high-angled summer sun while admitting low-angled winter rays.

The cold night sky can serve as a heat sink for the radiative cooling of a building during day. Heat will flow from a warm atrium to cooler areas (radiative heat loss).

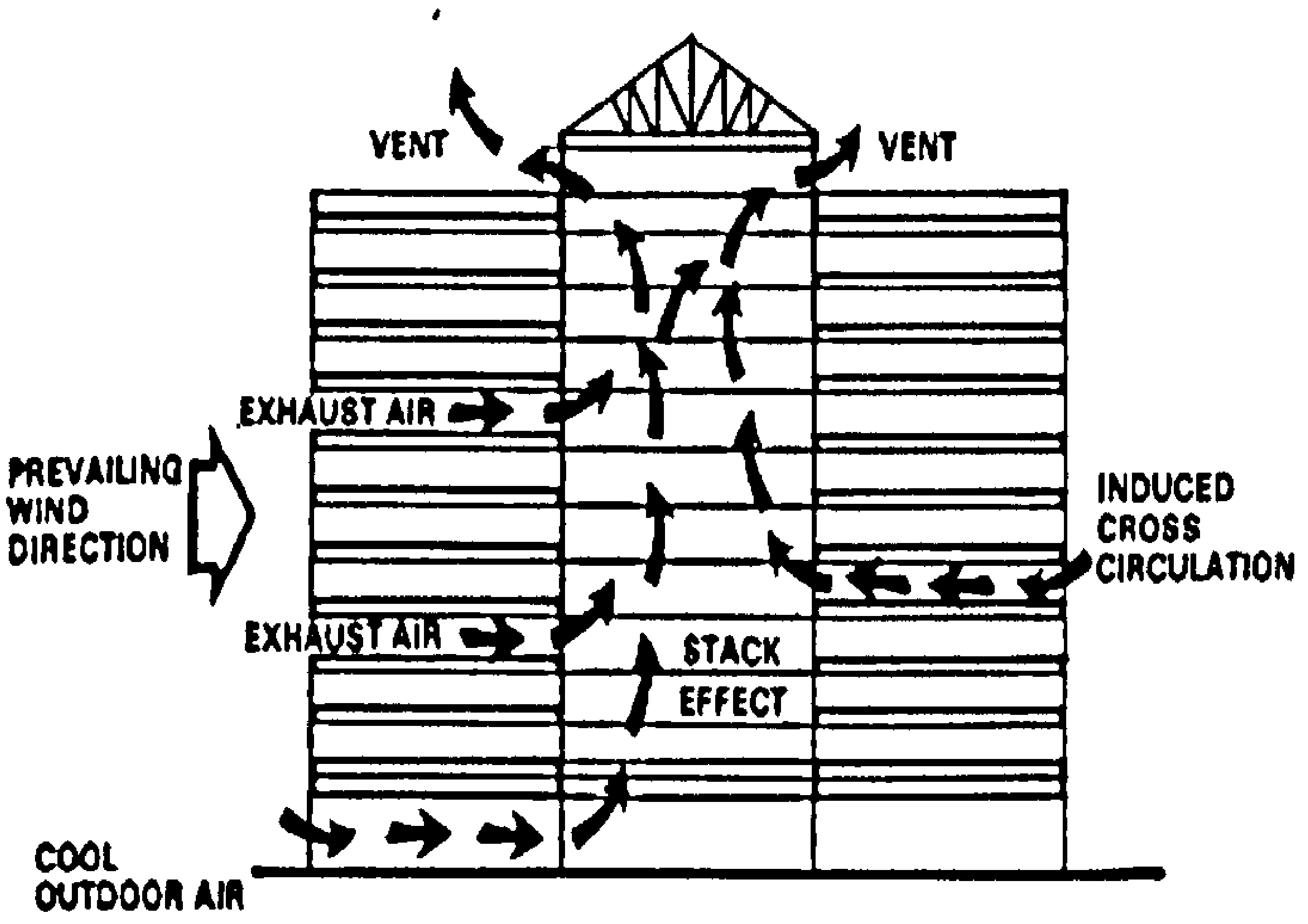


Figure 2. 22: Thermally driven and wind-induced atrium convection [Bednar, 1986]

Convective cooling is based upon the stack effect described above. Air of different temperatures are naturally stratified in the atrium well, creating a vertical pressure differential. The hot air can find an outlet at the top of the glazed roof, drawing air from surrounding spaces to fill the vacuum and thereby setting convective flows.

The thermal mass of the building can aid in the cooling strategy by reducing the building temperature at night with the use of night ventilation. Cool night air, often with mechanical aid, can be driven through the building in order to reduce the temperature of its mass components.

2.3.2.3 Natural lighting

An unheated, glazed atrium allows us to increase the sizes of glazed areas to spaces 'looking in' to the atrium, thus improving the potential for natural daylight to replace electric light in those spaces, while potentially reducing heating losses from the whole building. This reduction in electric lighting could be of major impact in energy savings, as it is typically the primary cause of energy consumption in commercial and office buildings.

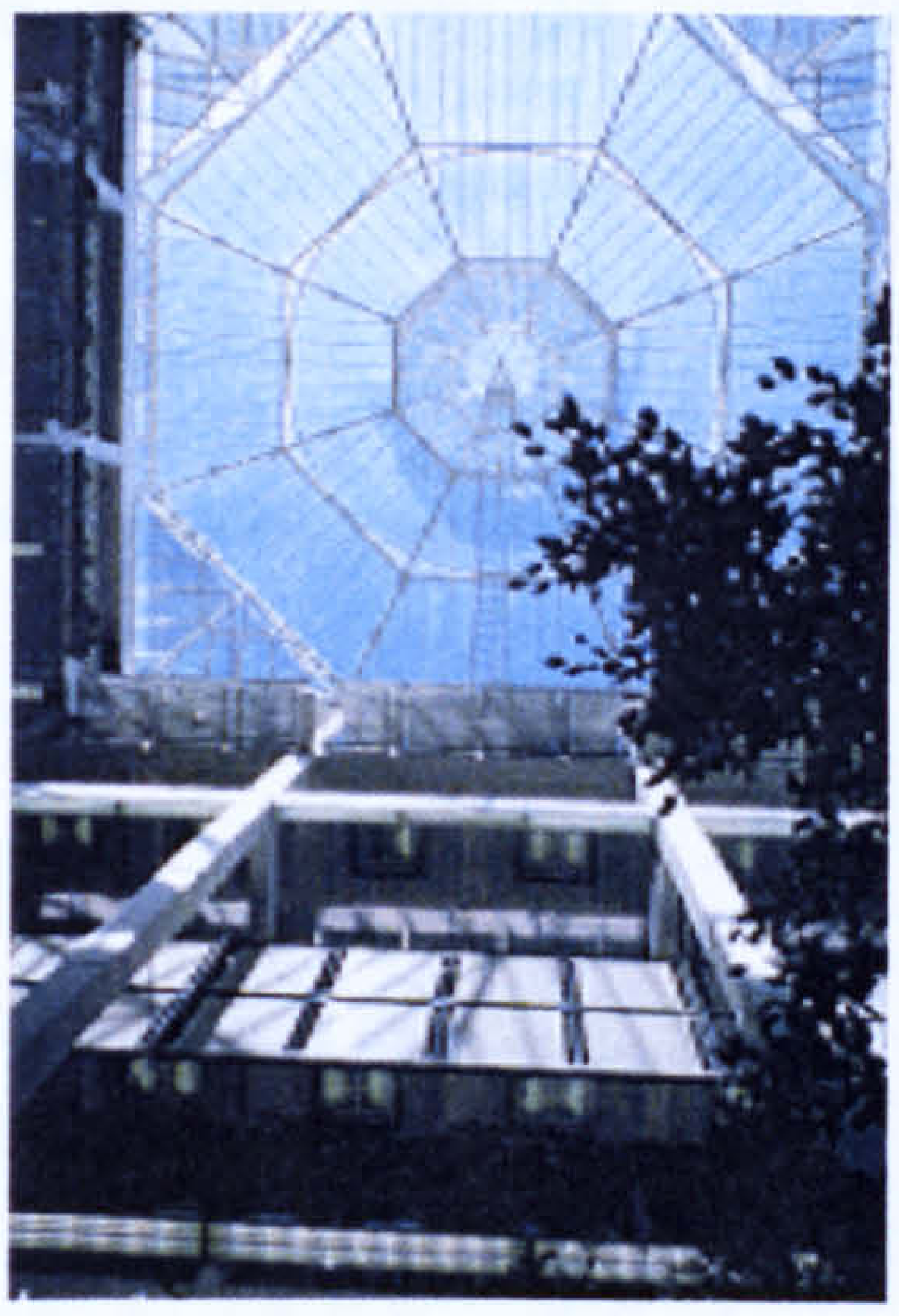


Figure 2. 23: An atrium defining the space; No1 Fins bury Avenue,New York [Saxon, 1983] (left)

Figure 2.24: An atrium animating the space: Imperial War Museum, London [Saxon, 1983](right)

One of the most significant concerns in daylighting an atrium is to determine the daylighting "task" of the space rather than the building type, i.e., whether the atrium daylighting role is restricted to the atrium floor only, the occupied spaces, or both. For example, atria, which serve as circulation spaces will normally have the same lighting criteria whether they are located in office buildings or hospitals. In some cases, minimum lighting design conditions may be dictated by the luminance requirements of plants rather than by people who pass through. According to Baker et al (1993), the level for daylight needed in an atrium is coupled to its use: if the principal requirement is for a pleasant view, then the daylight must be sufficient merely to provide a bright, lively atmosphere (a daylight factor of 5% to 10%) and to sustain any planting (a daylight factor of 5% to 40%) .If the requirement is to save energy in adjoining spaces by displacing electric lighting, then even higher levels of daylight may be required in the atrium, with the risk of glare and overheating.

The light distribution is another concern for the designer. Lam (1986), divides the top lit shared central spaces into Courts, Atria, Lightcourts, Litria, and Lightwells, depending on the way they capture and distribute daylighting (Figure 2.25).
Courtyards and atria are described as central spaces created primarily for human pleasure, though they do have some sunlighting implications. Lightcourt, litria and lightwells are described to have evolved from the courtyard and atrium forms. They express the effectiveness of sunlighting; the light reflecting and controlling qualities of their central spaces are maximized in order to provide sunlighting for the surrounding spaces.

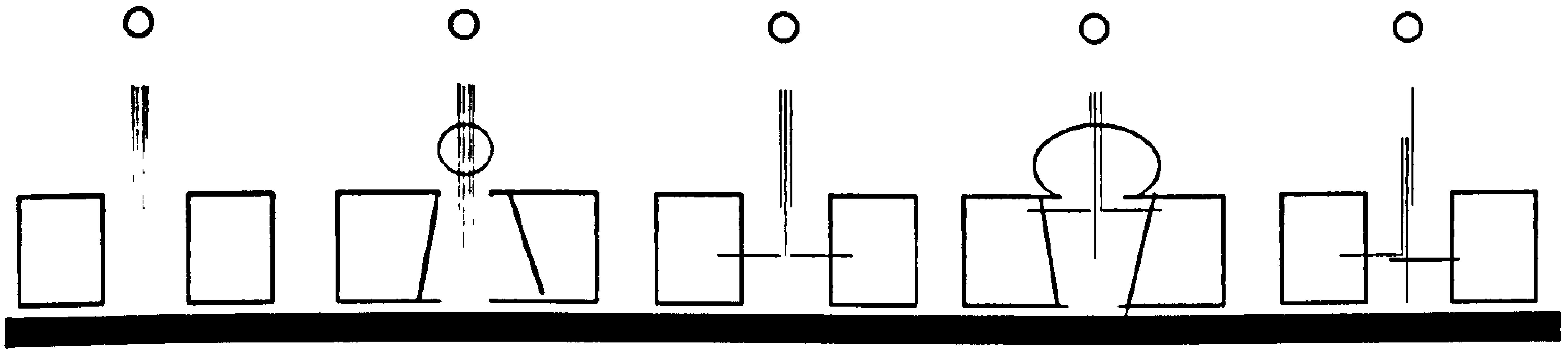


Figure 2. 25: (from left to right)Court, Atrium, Lightcourt, Litrium, Lightwell

The benefits of natural lighting within the atrium spaces can vary from the energy cost point of view, to the visual comfort in the adjacent buildings as well as possible psychological benefits.

Climate is considered as the most important influence on the way light can be admitted into an atrium. A number of different approaches are suitable in different climates, i.e. there are places where skies are often cloudy, those where they are usually clear, temperate climates and those with extremes of daily and annual conditions. In a climate like the Mediterranean, where there is plenty of sunshine during the largest part of the year, daylight control becomes a difficult task: sunlight is too harsh and shadow too dark. Therefore, sunlight must either be excluded by shades or converted to diffuse light. For example, in this type of climate, the type of polar saw-tooth roof will deliver plenty of useful diffuse light (Figure 2.26, Figure 2.27).

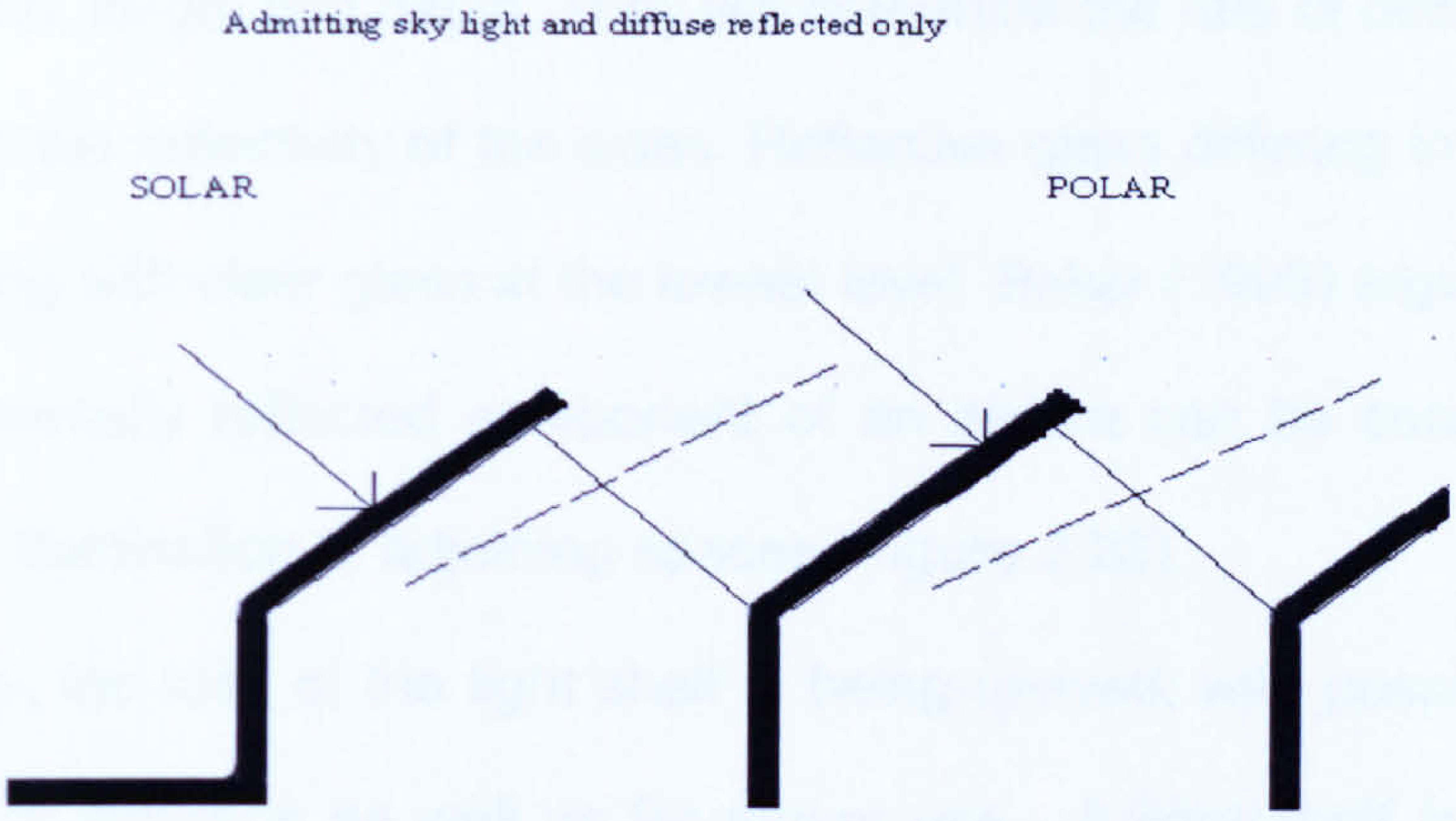


Figure 2. 26: Polar saw- tooth roof for sunny warm climates

Figure 2. 27: An example of saw-tooth atrium roof in Ioannina, Greece

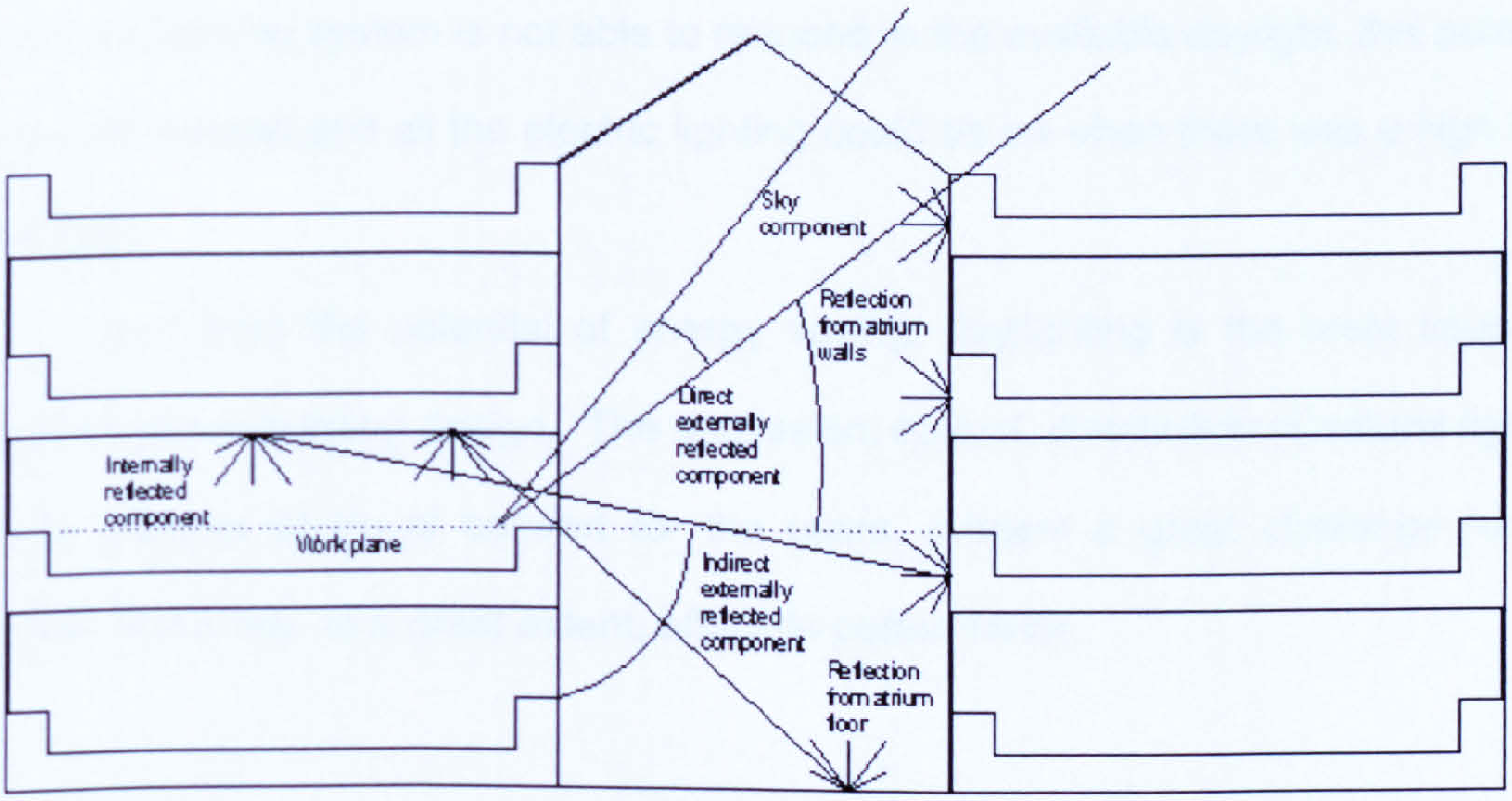


Figure 2. 28: The atrium as a source of daylight for adjacent spaces [Baker, 1993]

Another important issue is the way that light is distributed within the atrium space. The atrium acts as a light duct. Openings into occupied spaces are its outlets, but it is the walls of the duct, which determine how much light gets to the bottom and into the lower storey of the building. The parameters that play a key role are the ratio between its width, length and depth. They will determine the rate of decay of light levels in the court and the reflectivity of the sides. Reflective glass differing in strengths could be used, finishing with clear glass at the lowest level. Baker (1993) argues that both the sky and the internally reflected component of an atrium can be considered as light sources for the illumination of adjoining spaces (Figure 2.28).

Recently, the idea of the light shelf is being revived, with possible applications to the exterior of buildings as well as for atrium use. A light shelf is a horizontal or inclined baffle in the window, placed just above eye level but as far below ceiling level as possible. Sunlight and diffuse light are stopped from passing straight to the floor close to the window, and reflected back onto the ceiling.

The final aspect of daylighting in atrium spaces discussed here is the integration of natural and artificial lighting. For daylight to make a real contribution to energy efficiency it is not enough that it should just be admitted into the building; appropriate lighting controls are essential. There maybe energy saving potential, but if the electric lighting system is not able to respond to the available daylight, this potential will not be realized and all the electric lighting could be on when there was a high level of daylight.

Apart from the potential of energy saving, daylighting is the most important aspect of atrium building design. The admission, control, distribution of natural light as well as aspects of visual comfort for the users, present a great challenge for the designer and it can, to a great extent, affect its performance.

2.4 Atrium Buildings in Mediterranean Climate

Atrium buildings are widely spread in northern countries. This can be explained considering the urban qualities, amenity and potential energy conservation properties of these spaces. However, in warmer climates, more specifically in Mediterranean countries, spaces covered with glass can result into higher temperature environments.

This part of the chapter enables two very important aspects of this thesis to be investigated: first the variety of types of modern glazed spaces that exist in a Mediterranean climate, and secondly the conditions occurring inside these spaces, especially during summer period when high external temperatures can create uncomfortable conditions.

What follows is "a virtual trip" of atrium buildings in Greece through a short presentation of case studies and examples of their use (urban links, shopping malls and other types of buildings), and their design (materials, structure, roof shape, ventilation techniques, etc), both in existing buildings and proposed structures as well as potential retrofitting or redesigning of buildings.

By visiting a number of atrium buildings in Greece, there was the opportunity of identifying all those different functions, building types and materials, as well as obtaining important information from the users by surveys and observation. There were more than 20 buildings visited, in different climatic regions of Greece. An important outcome is that due to all the different sizes, types, materials, functions, and most importantly, climatic differences, none of the atrium buildings could be compared with another.

2.4.1 Forms & Functions

A review of historical examples and modern case studies suggests that atria serve many functions in a variety of building types. As stated before, a primary intent in many modern buildings is to use the atrium as a climate-modification strategy or thermal buffer zone to make "outdoor" space more comfortable and usable for more time during the year.

Figure 2. 29: An example of an enclosed glazed space. The old Post Office in Thessalonica

Atrium buildings, glazed courtyards, glazed-covered streets, gallerias and shopping malls can be found all around the Mediterranean region. In the beginning of the chapter there were four basic generic forms of glazed spaces selected: closed, semi-enclosed, linear and attached. Each of these types can be identified in the following examples. The term "function" in this text applies to both the buildings' role in the urban context as well as its use i.e. the activities that take place.

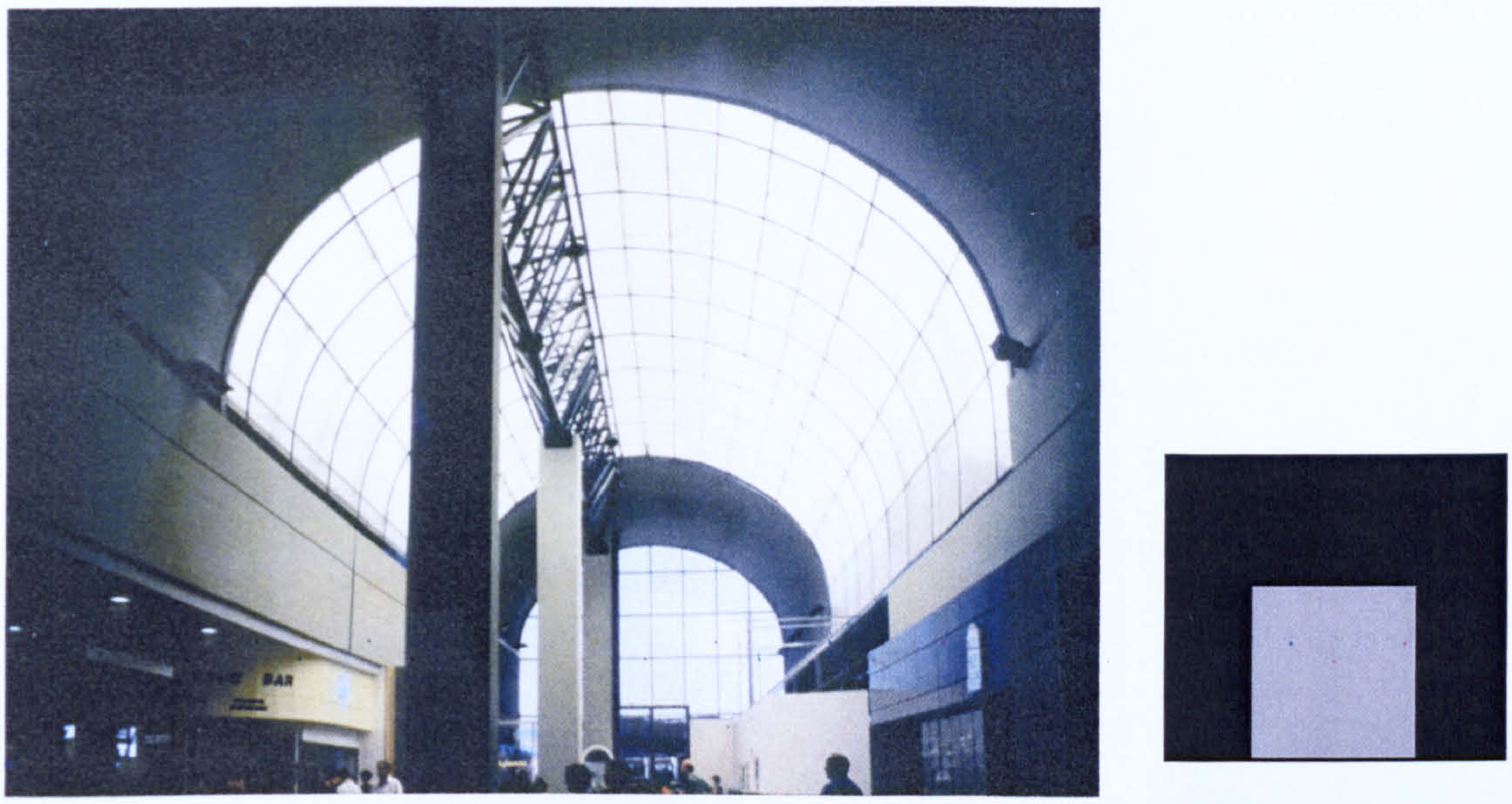


Figure 2. 30: An example of a semi-enclosed glazed space. Macedonia Airport in Thessalonica

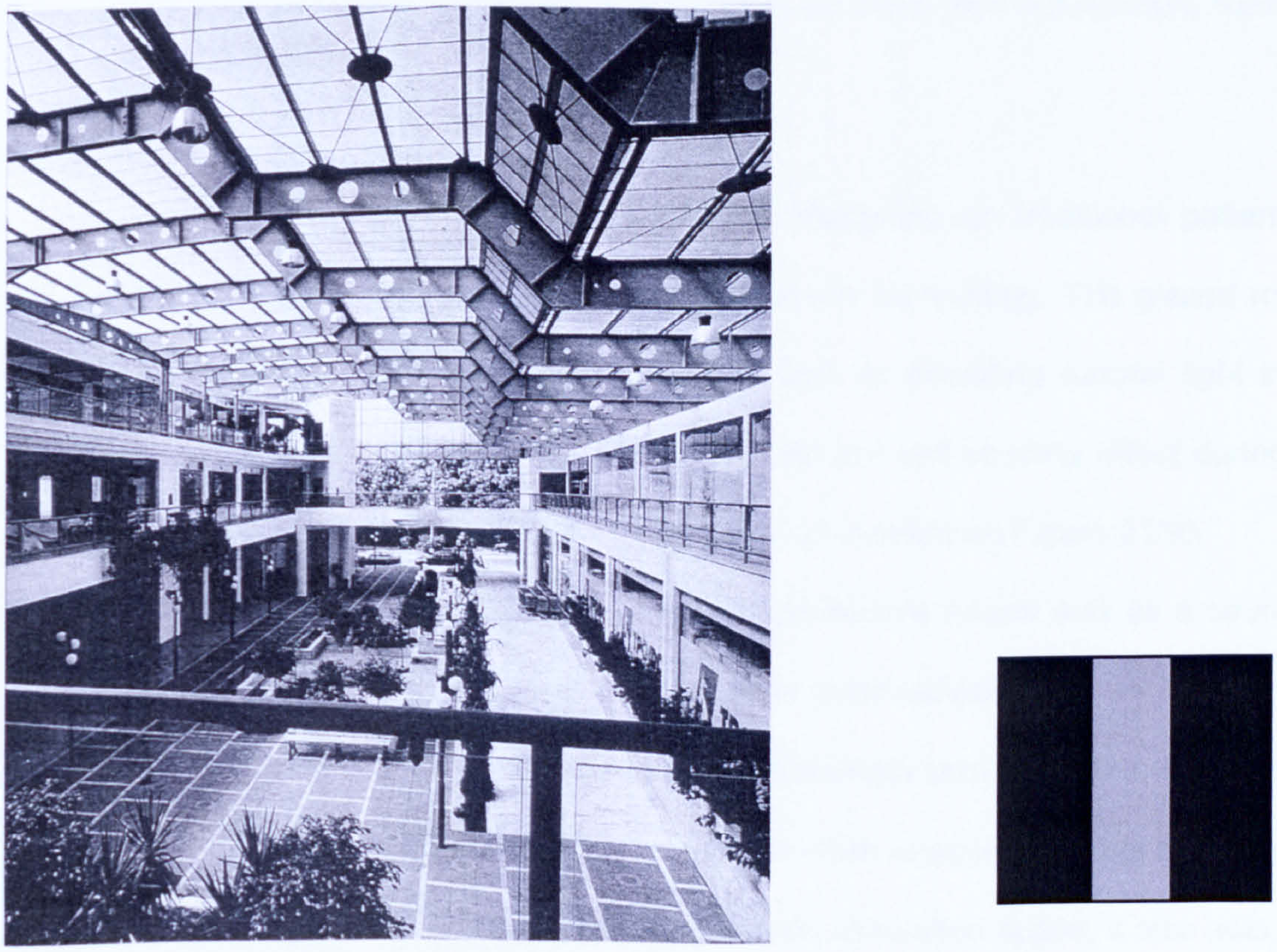


Figure 2. 31: An example of a linear glazed space. Office building in Kalamata

Figure 2. 32: An example of an attached glazed space. Administration headquarters building of the Credit Bank in Athens

The above figures illustrate examples of designing on traditional patterns of space and climate modification, and on contemporary technology. The glazed roof in Thessaloniki's old Post Office, uses the atrium well for providing natural light in the adjacent deep planned office rooms in winter, while the self-shading effect during the summer, provides a cool ground floor inlet for natural ventilation (Figure 2.29).

The fabric-covered cylindrical roof in the Macedonia Airport acts as a source of natural light while protecting the space from intense solar radiation (Figure 2.30).

The linear atrium in an office building in Kalamata provides an excellent inlet-outlet axis for natural ventilation through the space while enabling the use of the space all year round (Figure 2.31). Apart from being a main circulation space, it also acts as a social gathering spot.

The attached glazed space of 3-5 storeys height in the administrative headquarters of the Credit bank in Athens enables the co-existence of traditional and modern materials and the visual communication with the outside urban environment. This dynamic design is an expression of a prestigious corporation (Figure 2.32).

Figure 2. 33: "Stoa", glazed pedestrian street in Athens, Greece.

Amongst the most common types of glazed spaces in the Mediterranean region are the gallerias, glassed-covered pedestrian streets. In the city scale they function as urban links and at the same time as transitional spaces by providing shade and shelter from external weather conditions.

Urban designers use these types of glazed spaces to provide more sympathetic building masses and good pedestrian routes in cities. The emergence of the ideas of shopping street and public square, in their covered forms, as galleria and atria is one of the intriguing design developments (Figure 2.33, Figure 2.34).

The functional benefits of these spaces have been discussed and analysed in a previous part of this chapter; by visiting a number of these spaces, in hot summer conditions, it was observed that the environment was pleasantly warm, compared to the hot ambient temperature. The presence of cafes and other sitting spots provides a refreshing stop as well as a progressive, and therefore more comfortable passage from an internal to an external environment.

Figure 2. 34:"Stoa" in Athens, Greece. The opening in the middle of the stoa enables the creation of a resting area with benches and cafes

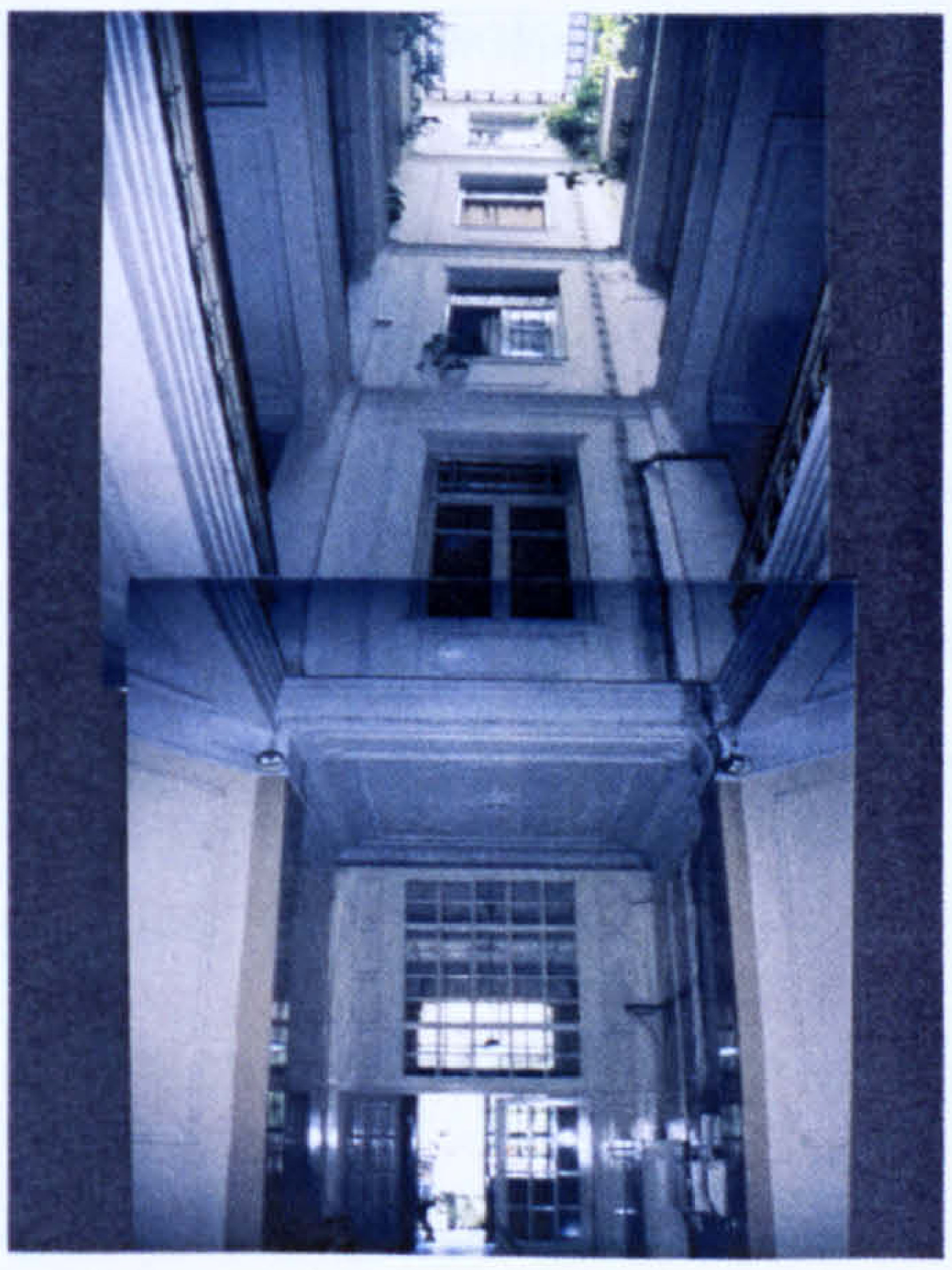


Figure 2. 35: The atrium in office block in Thessalonica, Greece

A glazed space often acts as a lantern in deep-planed, tall buildings and they are quite helpful in an overall ventilation system. This is the case in many 60's buildings in the city centre of Thessaloniki (Figure 2.35).

The majority of the glazed spaces visited were free running. They also allowed an increase proportion of glazing overlooking the atrium, thus improving the potential for natural daylight to replace electric light in those spaces, while providing the potential of reducing heating losses for the whole building. As such, the atrium may become a useful intermediate space for climate tolerant functions such as circulation, shopping and exhibitions. Used in this way an atrium can perform as a covered pedestrian street or square, blocking out wind, rain, pollution and noise and modifying the temperature and light levels. Experience has shown that such atria are often attractive and interesting places to be in and to look into from surrounding spaces.

A large amount of shopping centres incorporate an atrium in their design, simply because of the visual dynamics of the space created; the multi-storey proportions that can be grasped in a glimpse and the utilisation of daylight. In such places there is strong presence of plants and quite often of water features. The colours, sounds and smells, as well as the presence of natural light, are amongst the virtues of the space created.

Most atriums visited are unacquainted to their antecedents in the Greek or Roman courtyard house, and the atrium image has come to mean the space on a large scale. Similarly, large scale in an atrium creates a very dynamic space, while in a smaller scale created a much more sophisticated environment.

Apart from shopping centres and gallerias (Figures 2.36-2.39), this research showed that atria are also incorporated in large buildings such as hospitals, educational buildings (Universities, Educational & Training centres), industrial buildings and other public buildings such as the new building of the Greek National Statistical Service (Figure 2.40). In such large buildings, atria can play a very significant role, by allowing the users to orientate themselves easily, providing at the same time a focal point used as reception, resting area etc. The majority of them were designed as passive solar systems contributing to the reduction of heating and cooling loads of the adjacent buildings.

Figure 2. 36 & Figure 2. 37: Shopping Centres in Glifada, Athens

Figure 2. 38 & Figure 2. 39: Shopping Centres in Glifada, Athens

In the case of the new building of the Greek National Statistical Service, there was a vigilant environmental design and energy estimation from C.R.E.S. (Centre for Renewable Energy Sources). It was reported (Oikonomidis, 1997) that there would be a considerable contribution from direct solar gain (which includes the 2 atria) for both the heating and cooling loads of the buildings. Two of the main functions of the atria are to bring natural light into the lowest floors of the building and to enhance natural ventilation –solar chimney effect. Special reflectors have been placed to distribute diffused daylight while the roof is equipped with specially designed movable metallic louvers for adequate solar protection.

Figure 2. 40: Perspective view and section of the building of the Greek National Statistical Service (GNSS), in Piraeus. The section shows one of the two atria incorporated.

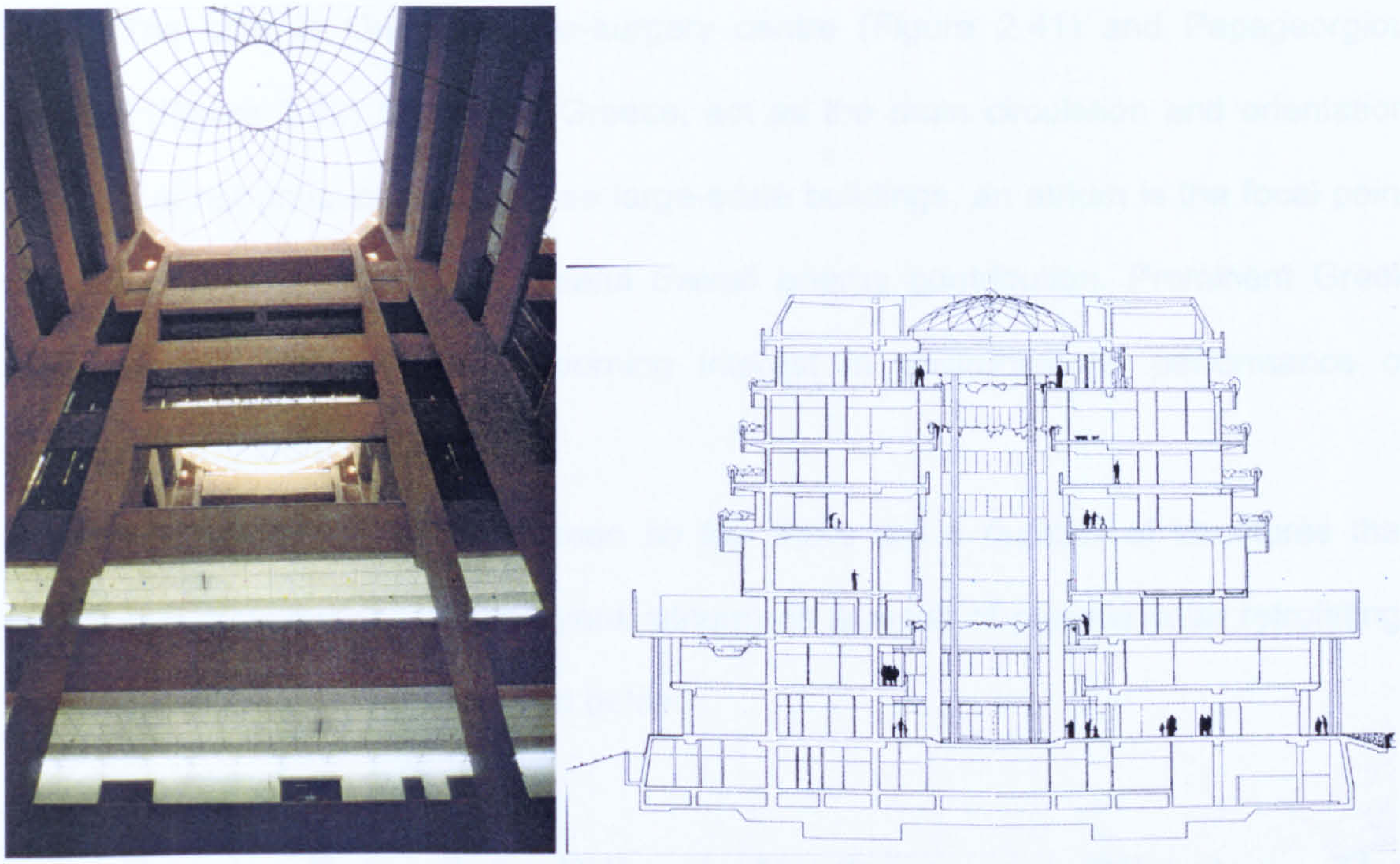


Figure 2. 41: Onasio cardio-surgery centre, in Athens Greece, view of the interior atrium space of the building and cross-section

Figure 2. 42: The atrium in the Papageorgiou Hospital, Thessaloniki

The atria in Onasio cardio-surgery centre (Figure 2.41) and Papageorgiou Hospital (Figure 2.42) in Athens, Greece, act as the main circulation and orientation space. It is not unusual that in these large-scale buildings, an atrium is the focal point with an aesthetic value and a useful overall energy contribution. Prominent Greek architects that have shown a looming interest in environmental performance of buildings designed both buildings.

Apart from the buildings seen so far, there are a number of structures that incorporate a glazed space (courtyard, atrium) as a result of passive solar retrofitting, some cases of which are discussed below.

2.4.2 Passive Solar Retrofitting in Mediterranean Climates – The Case of the Atrium Building

The building conservation movement uses atria to revive old buildings, either those with existing courts or covered halls, or those too deep-planned to be used without hollowing out. By adding a glazed roof in an existing courtyard we can create a space where the microclimate can be controlled to provide richly varied places for people and plants throughout the year (Watson, 1982).

Most passive solar systems are applied to new constructions where the design possibilities offered to the specialist are unlimited. This is not the case in retrofit applications where the building shape and location are fixed and incorporation of a given system is much more dependent on the designer's skills.

Energy-conscious designers use atria carefully as passive solar climate-controllers. Although retrofitting could offer many advantages in terms of energy saving for the adjacent buildings (where they can cover a very important percentage of the heating or cooling load of buildings with very low added cost) it presents inherent limitations for the designer; the buildings shape and location are fixed and incorporation of a given system is much more dependent on the designer's skills (Trianti, 1988).

Figure 2. 43: Passive solar retrofit in the building of Fondazione Querini Stampalia, in Venice.

In the building of Fondazione Querini Stampalia, in Venice (Figure 2.43), the design of architect Mario Botta was a conversion of two small open courtyards into one single glazed courtyard. When the building was visited (February 2002) the architect was carrying out a number of design experiments for shading and protection from excessive heat gain and the adequate ventilation of the space.

In spite of the difficulties inherent in such applications, it is obvious that low-cost retrofit solutions of passive solar systems may cover a much higher percentage of the building stock than those addressed to new buildings in rural of suburban areas; as such, they could also contribute to the formation of a new "solar" or "energy conservation" conscience for a much wider segment of the population in cities and larger towns.

The semi-controlled exterior spaces thus created in close relation to the building offered many social and cultural advantages especially if fitted to large educational and public buildings. Some of these courts were often glazed over in later times, using already developed greenhouse technology to transform the courtyard into a covered public or private gallery always in close contact with nature. Such examples are quite popular in modern architecture as well, where atrium buildings are designed to create such retrofitting is the atrium in the Philosophic School at the University of Ioannina, Greece (Figure 2.44). This building will be used as a case study for comfort analysis and energy performance in the current research and the results will be discussed in the following chapter.

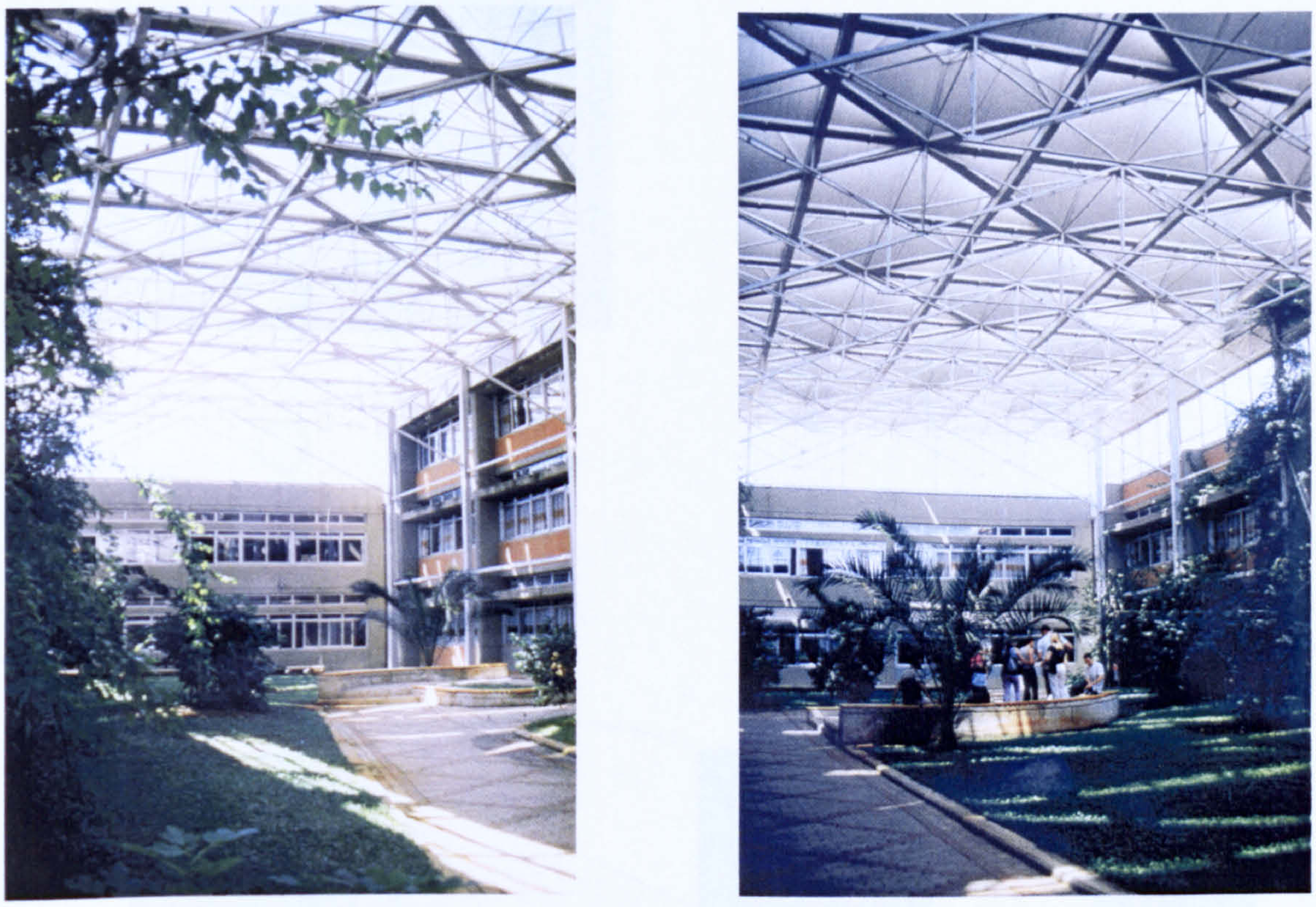


Figure 2. 44:The atrium building in the Philosophic School at the University of Ioannina, Greece. The building is typical case of retrofitting and the pictures show the atrium in winter

From the passive solar design point of view, and since atrium spaces are not dependent on building street facade orientation, design systems adapted to them can be used not only for housing but also for larger building and building complexes, even whole central town blocks.

In large Greek cities like Athens and Thessalonica (where 50% of the population of Greece is accommodated), the unit of urban development, the urban plot, is delineated by the rectangular patterns of the streets (Figure 2.45). The shape of a representative plot ranges commonly from squares 40m by 40m to rectangular 40m by 100m. The buildings, situated along the perimeter of the plots are typically five to seven storeys high, often with top floors set back from the street façade (due to building regulations).

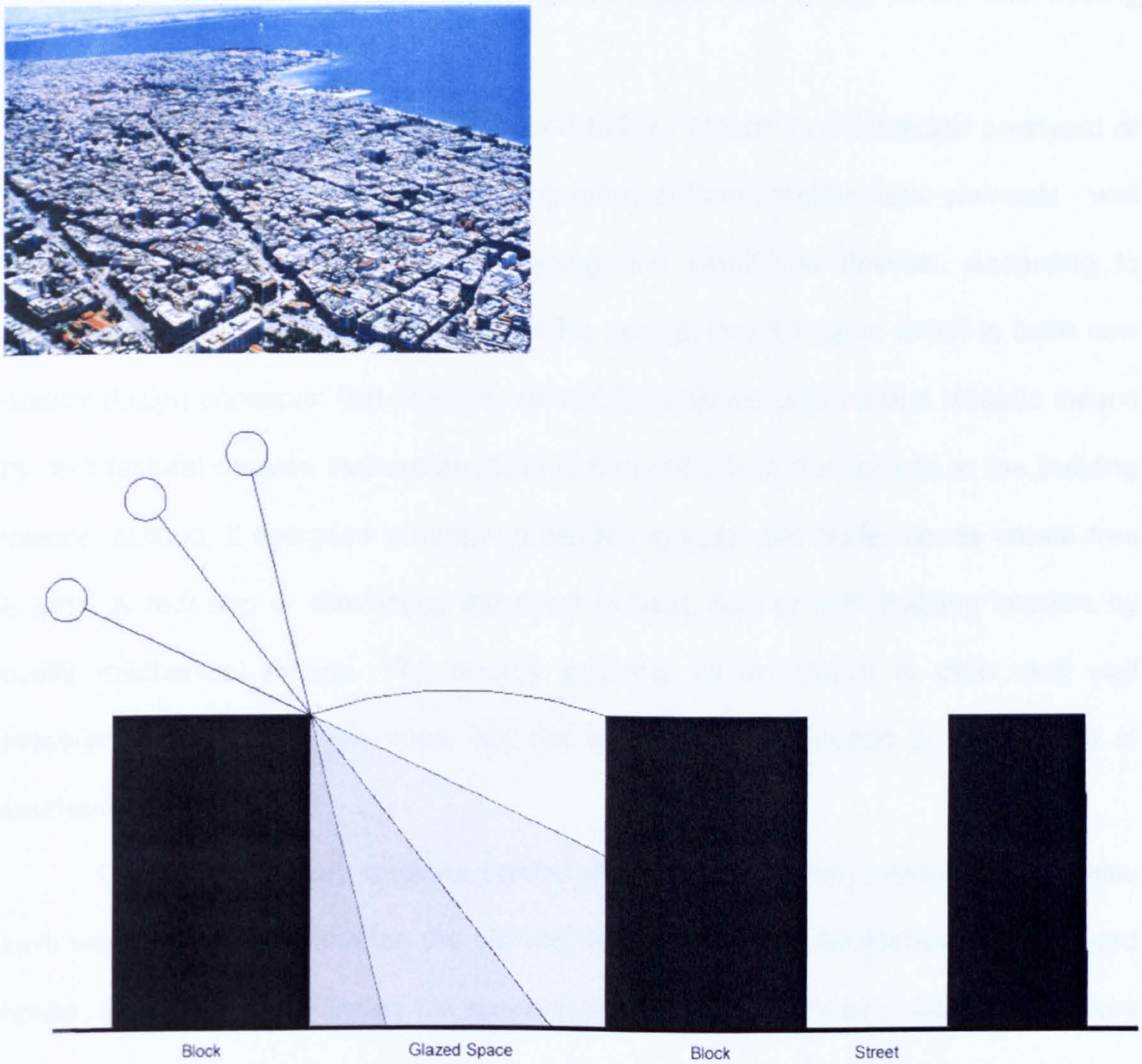


Figure 2. 45: Aerial photo of Thessalonica showing the dense urban environment (above left). Passive solar retrofit by glazing the space between two blocks (above).

2.4.3 Design & Energy Potential of Atrium Buildings in Mediterranean Climate

Before any design strategies can be discussed, there are two basic issues a designer has to consider: the climate of the site and the thermal nature of the building.

The climate is obviously a deciding factor: buildings in cool climates need heat for most of the year; on the other hand, buildings in the tropics need constant cooling. Buildings in a climate like the Mediterranean need heat during winter and cooling during summer.

Generally, as the term is often used today, "atrium" is a protected courtyard or glazed void within a building, incorporating many different architectural elements - wall enclosures, sun-oriented openings, shading and ventilation devices. According to Donald Watson (1982), atrium buildings offer several lessons upon which to base new energy design concepts: first, human comfort is achieved with natural climatic means by architectural devices that create gradual transition from the outside to the building interior; second, if designed properly, protected spaces and buffer zones create free energy by reducing or eliminating the need to heat, cool or light building interiors by costly mechanical means. The energy potential of an atrium is clear and well established in northern countries, but not adequately researched in the context of southern latitudes.

One of the primary reasons behind the inception of the ancient atrium house form was its ability to enhance the climate. In the traditional Mediterranean courtyard house, the atrium walls shaded the space in summer. The night air-cooled the masonry atrium surfaces, allowing them to absorb heat from adjacent spaces during the daytime. Cross circulation from the perimeter of the house up through the courtyard top was induced by thermal and wind-driven convection flows. Stored rainwater provided additional evaporative and radiative cooling. In winter, the opening to the sky brought in solar heat to be stored in the masonry walls and floor. Daylight was available in all seasons to support the activities of living. All characteristics of this design, work as a co-ordinated energy system, which compensates diurnal and seasonal climatic variations by utilising natural energy flows (Figure 2.46).

Not all of those features present in the open-air Mediterranean courtyard house are realistically possible in the enclosed atria. An atrium designed for energy efficiency should make maximum use of passive energy flows alone or in concert with mechanical energy systems.

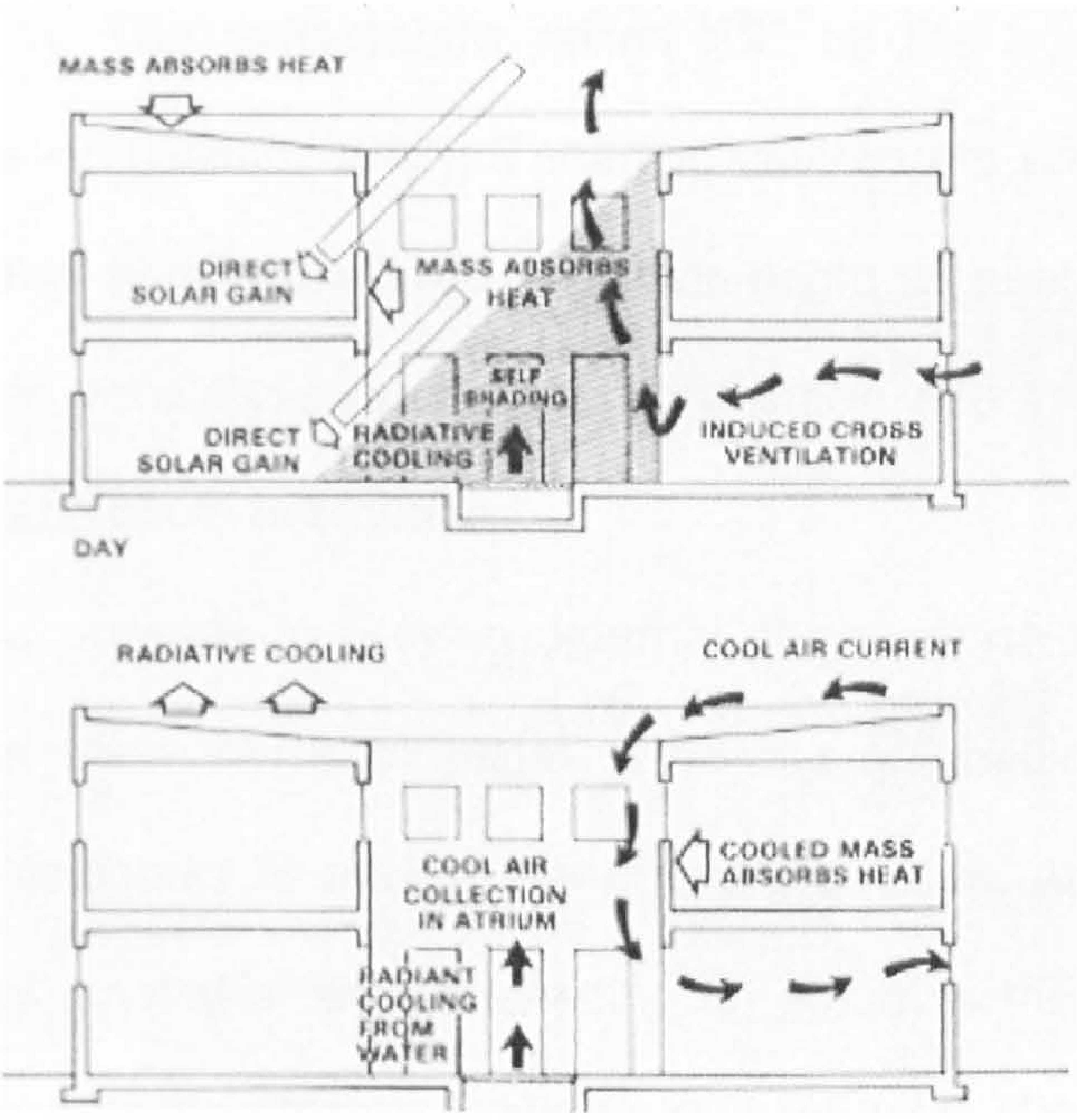


Figure 2. 46: The Mediterranean House [Bednar, 1986]

A modern atrium in the Mediterranean climate should work as a warming atrium in winter, but have substantial defences against over-heating in summer. This is the case even when full comfort is not sought in the atrium itself, otherwise solar impact on the atrium interior will lead to heat build-up in the occupied space, and to impractical ventilation rates in the atrium.

In summer the main concern is to prevent overheating. Even if is difficult to reduce air temperatures in the atrium below ambient temperature throughout the day; this may be possible during the morning. Overnight ventilation when the air temperature is below the daily average, may obtain that result. However, the basic need is for external shading to the atrium glazing. This can be fixed to admit low-angle sun in winter but to exclude high-angle sun in summer, or it can be operable.

As stated before, apart from providing natural illumination, daylight can contribute to a considerable reduction of artificial lighting, which is one of the main source of heat generated in the occupied space, therefore helps to save energy and reduce cooling loads.

The internal spaces on upper floors in a warm climate like the Mediterranean collect solar radiation. The temperature raises 1^0C by the height 1m due to the temperature stratification (Saxon, 1983). If shading devices are adapted inside, heat is gathered under the roof and mechanical ventilation might be needed. Optimal cool air ventilation or natural ventilation re-circulated by stack effect can be adopted to minimize heat gains and avoid overheating.

However, it is possible to provide external shade, since the atrium envelope provides a structure upon which to install a variety of shading devices. Current technology enables designers to realise any possible solution. An example of a very successful as well as innovative way of shading an atrium is the one adopted in the shopping centre near Estacao Oriente in Lisbon (Figure 2.47). The curved glazed roof incorporates internal perforated metallic sheets, which controls the amount of natural light in the space. Along the main axis of the atrium, a metallic tube releases water, which is collected in scuppers around the atrium roof and recycled. Water, cools the external surface of the glazing materials adding to the summer cooling, while its movement is reflected on the walls and floor of the atrium, adding to its aesthetic value.

Another potential of a glazed space, as seen in the context of the Mediterranean climate, is the capacity to link urban environments enhancing the transition from one place to another. Additionally, because of the presence of natural light, the atrium space can host a number of plants and therefore become an exciting environment. An example that combines all the above is the Yapi Kredi Bank Operations Centre in Istanbul, which incorporates administrative, operational, training, conference and social accommodation, enclosed by a series of fabric-covered internal streets, which unite the whole development (Figure 2.48). Both Yapi Kredi's company culture and the covered markets and courtyard forms of traditional Turkish Ottoman architecture have inspired the design approach. The design particularly responds to energy conservation issues and technological construction opportunities.

(left) Figure 2. 47: The atrium building in Estacao Oriente in Lisbon

(right) Figure 2. 48: The Yapi Kredi Bank Operations Centre in Istanbul

However, before any strategy can be turned into a design, another important factor has to be addressed: the degree of comfort required in the atrium space itself. Therefore it has to be considered whether the atrium space will be conditioned or take advantage of its thermal processes and be a free running building. Often, not fully appreciated, is the opportunity presented by a properly designed atrium as an unconditioned space, requiring no other energy than that available to it in its position as buffer zone between exterior and interior.

Thermal comfort is further discussed in the following paragraphs.

2.5 Thermal Comfort

2.5.1 What is Thermal Comfort?

The thermal interaction between man and the environment is highly complex and has been the subject of a great deal of study. Man has always struggled to create a thermally comfortable environment. This is reflected in building traditions around the world - from ancient history to present day. Today, creating a thermally comfortable environment is still one of the most important parameters to be considered when designing buildings.

The design of buildings and the choice of building materials owe a great deal to the external climate and thermal, optical and acoustical requirements of human beings (Bansal 1994). The interior conditions of a building can be improved very close to the desired level by a thorough environmental design of the building, as well as with the proper selection of materials. As a preliminary step to building design, it is necessary to have an understanding of the indoor conditions that are preferred and those that should be avoided. These conditions should serve as guidelines in assessing the range of values of parameters in order to create comfortable conditions.

With respect to comfort inside the buildings, it is possible to distinguish between thermal comfort, lighting and acoustics. The most important of these effects is thermal comfort (Bansal 1994).

Thermal Comfort is defined in the ISO 7730 (1995) standard and by ASHRAE (1993) as being "*that condition of mind which expresses satisfaction with the thermal environment*". A definition most people can agree on, but also a definition, which is not easily converted into physical parameters. The condition of thermal comfort is also sometimes defined, as "*a state in which there are no impulses to correct the environment by behaviour*" (Benzinger 1979). This is a more objective definition than the ISO definition. Thermal environments are considered together with other factors such as air quality, light and noise level.

2.5.2 Thermal Comfort Parameters

Man considers the environment comfortable if no type of thermal discomfort is present. The first comfort condition is thermal neutrality, which means that a person feels neither too warm nor too cold. The major aim of comfort research is to define comfort temperature for an individual or group.

Earlier research (Fanger 1972), (McIntyre 1980) has shown that thermal comfort is strongly related to the thermal balance of the body. This balance is influenced by:

- Environmental parameters: air temperature (T_a) and mean radiant temperature (T_r), relative humidity (RH) and relative air velocity (v)
- Personal parameters: activity level or metabolic rate (M) (units: 1 met=58 W m^{-2}) and thermal insulation normally provided by clothing (I_{cl}) (units: 1clo= 0.155 m^{-2} K W^{-1})

Most of these basic parameters that affect thermal comfort are under the control of the design team; the rest, are controlled by the occupant.

Air Temperature is the basic control parameter for most buildings. **Relative Humidity** is the second parameter that can be controlled. There are other terms such as wet bulb and dew point to define the amount of moisture in the air. **Air movement** is the third aspect that can be controlled. The volume and condition of the air being moved, as well as where and how it is injected into the room are determined by the designer. The last design parameter is the **mean radiant temperature (MRT)** of the space. This is the average temperature of the walls, floor and ceiling--those surfaces that the occupant has radiant transfer with. If these surfaces are cold in winter (as in non-insulated walls or large glass areas), the occupant may feel cold, even though the room air temperature is higher than normal.

There are several parameters associated with the occupants. The **activity level** (measured in **METs**) of the occupants affects their comfort. The **clothing level** (measured in **clo**) also affects comfort. The **gender** of the occupant can also affect comfort: women have fewer blood vessels near their skin, and tend to need a slightly higher temperature to be comfortable than men (Fanger 1972).

The effects of all of these variables have been measured over the years and the existing data is a valuable guide for design for any controlled segment.

2.5.3 Thermal Comfort Scales

The subjective sensation of warmth, or thermal comfort, of a person has traditionally been measured using a seven-point scale. The subject is asked to rate his or her feelings on a descriptive scale such as the ASHRAE or the Bedford scales:

ASHRAE		BEDFORD
Hot	+3	Much too warm
Warm	+2	Too warm
Slightly warm	+1	Comfortably warm
Neutral	0	Comfortable neither warm nor cool
Slightly cool	-1	Comfortably cool
Cool	-2	Too cool
Cold	-3	Much too cool

The resulting number is called the Comfort Vote C. One of the problems arising with Comfort Vote is that, by using a descriptive scale there is a danger of overlapping with cultural use of the words. Thus a person living in a cold climate might see `warm' as having a positive connotation ("nice and warm"), whilst the inhabitant of a hot climate would say the same of `cool'. This will tend to bias the use of the scale by confusion between comfort and hotness. To get round this effect it is advisable to add a Preference Vote P to the Comfort vote, C. The preference vote most commonly used is the three-point one suggested by McIntyre:

I would like to be: +1: Warmer
0: No Change
-1: Cooler

The scales are arranged symmetrically about a "neutral" or "comfortable" category, the wording of the category description being symmetrical in the use of qualifying adjectives.

The Bedford scale is a combined estimate of warmth and comfort, and this feature has been criticized on the ground that the relation between the two is not necessarily constant. The ASHRAE scale by contrast, in its revised form, contains no explicit reference either to comfort or pleasantness (Humphreys 1976). The first aim is to discover what combination of environmental variables best describes the subjective responses of the subjects. To do this the researcher performs a statistical analysis of the data. Another type of analysis enables the proportion of people comfortable at any particular temperature (or combination of variables) to be calculated. The results obtained from any particular survey are specific to the survey, i.e. to that group of subjects in the environment encountered. The effect of experience, environment and climate are all part of the subjects' response.

The underlying assumption of the field survey is that people are able to act as meters of their environment. In effect, the subject is used as a comfort meter, not of temperature alone but of all the environmental and social variables simultaneously. The results obtained from such surveys are very specific to the conditions measured. Nevertheless the field survey is the key to understanding thermal comfort.

2.5.4 Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD).

If the thermal comfort in a workplace is not perfect, how far from perfect is it? Or within what limits should temperature and humidity be maintained to enable reasonable thermal comfort? Fanger extended the usefulness of his work by proposing a method by which the actual thermal sensation could be predicted. His assumption for this was that the sensation experienced by a person was a function of the physiological strain imposed on him by the environment. He calculated this extra load for people involved in climate chamber experiments and plotted their comfort vote against it. Thus he was able to predict what comfort vote would arise from a given set of environmental conditions for a given clothing insulation and metabolic rate. The answers to these questions can be obtained from the PMV-index (Predicted Mean Vote). The PMV-index predicts the mean value of the subjective ratings of a group of people in a given environment.

Fanger realized that the vote predicted was only the mean value to be expected from a group of people, and he extended the PMV to predict the proportion of any population who will be dissatisfied with the environment. A person's dissatisfaction was defined in terms of their comfort vote. The PMV scale is a seven-point thermal-sensation scale ranging from -3 (cold) to +3 (hot), where 0 represents the thermally neutral sensation, and is calculated by the general thermal comfort equation.

Another quantity, the PPD (Predicted Percentage of Dissatisfied) index, gives a quantitative predicted number of people who will not be satisfied with the thermal environment. PPD is defined by Fanger in terms of the PMV, and adds information about the interaction between people and their environment to that already available in PMV. The distribution of PPD is based on observations from climate chamber experiments and not from field measurements.

When the PMV index is estimated, the PPD index can be calculated from:

$$\mathbf{PPD = 100 - 95 * exp\ (-0.03353 * PMV - 0.2179 * PMV^2)} \qquad \textit{(ISO 7730: 1995)}$$

The relation between PMV and PPD is shown in Figure 2.49 and is important to note that the lowest value of PPD is 5%, which corresponds to PMV = 0. Thus, even if the PMV value predicts thermal neutrality, a person may feel local thermal discomfort.

That means that there will still be some individuals who are dissatisfied with the temperature level, regardless of the fact that they are all dressed similarly and have the same level of activity - comfort evaluation differs a little from person to person.

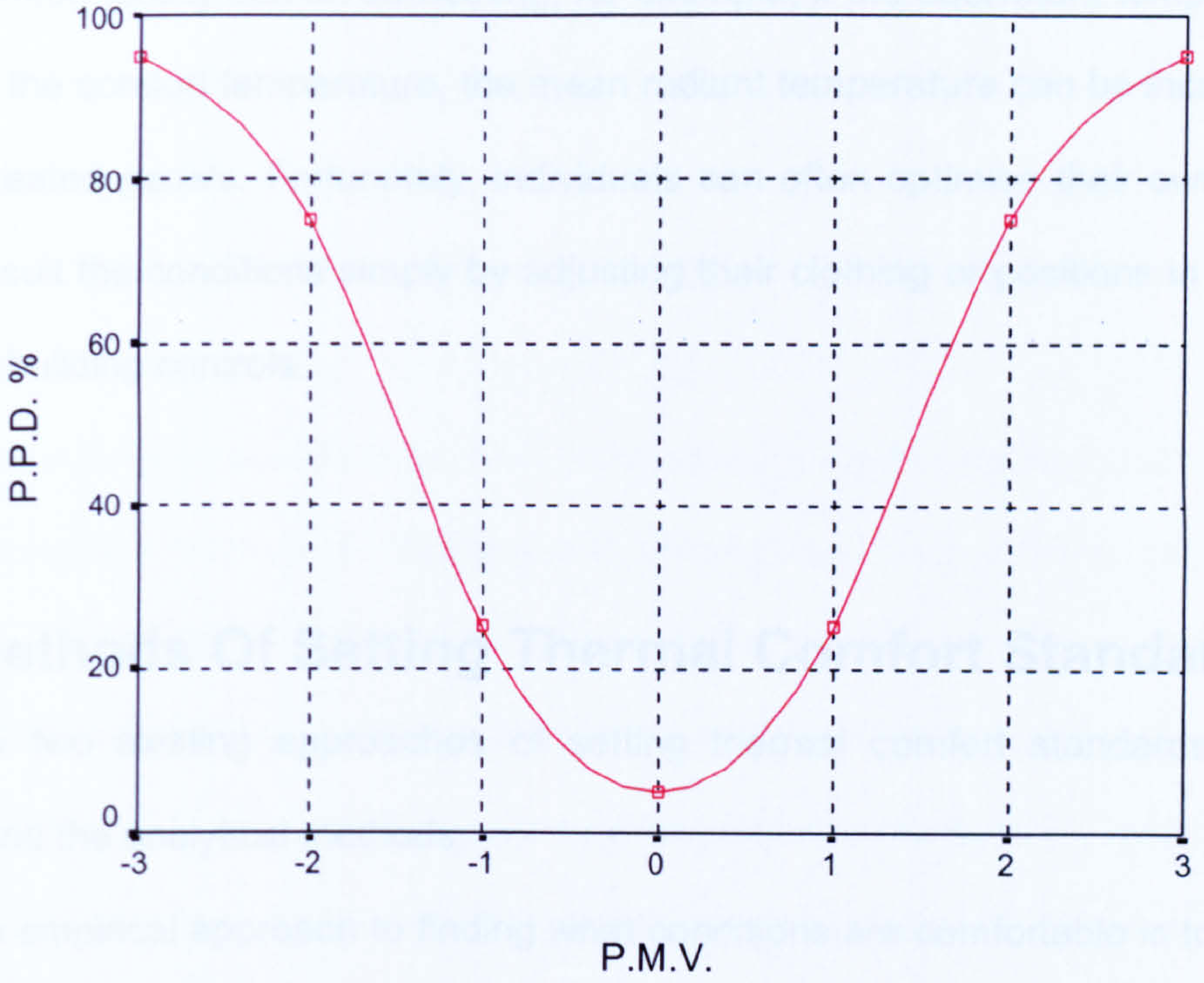


Figure 2. 49: Predicted Percentage of Dissatisfied (PPD %) as a function of the Predicted Mean Vote (PMV)

2.7.5 How to create Thermal Comfort

When describing the Comfortable Temperature (t_{co}), this is usually defined as the "equivalent temperature" where a person feels thermally comfortable (Fanger 1972) voting with the middle category of the comfort scale. The middle category is defined as comfortable on most scales.

The neutral temperature is the temperature at which people experience a sensation, which is neither slightly cool nor slightly warm and is expressed by voting the neutral or middle point of the seven point ASHRAE scale.

If a room contains many people, wearing different types of clothing and carrying out different types of activities, it can be difficult to create an environment, which provides thermal comfort for all the occupants. Changing the factors that affect the thermal comfort locally can do something; for example, if the equivalent temperature is lower than the comfort temperature, the mean radiant temperature can be increased by installing heated panels. Fortunately, individuals can often optimise their own thermal comfort to suit the conditions simply by adjusting their clothing or positions in the room or even by building controls.

2.6 Methods Of Setting Thermal Comfort Standards

The two existing approaches of setting thermal comfort standards are the empirical and the analytical methods.

The empirical approach to finding what conditions are comfortable is to conduct surveys in the field (in situ). Conditions are left to vary, as they will and the subjects to dress and behave, as they would normally do. The experimenter then measures the physical characteristics of the environment and relates these to the subjects' feeling of warmth to find the relationship.

Experimental work can also be carried out in a climate chamber (analytical approach). Climate chambers are in effect laboratories, which enable the experimenter to adjust the environmental conditions with regard to air and radiant temperature, humidity and air velocity. Such chambers have been widely used in controlled experiments investigating the effect of physical parameters on comfort. This approach treats each component of the man-environment interaction separately.

2.6.1 Empirical field surveys

In the field survey the method is to ask subjects taking part in the survey to assess their thermal sensation on a subjective scale generally running from "too cold" to "too hot" (see comfort scales). This assessment- as discussed in a previous paragraph- is commonly known as the "Comfort Vote" .The environmental variables are measured at the same time as the subjective reactions are taken. The interest is generally in finding a temperature or a range of temperatures and other environmental variables which people in that context will find comfortable. Because the aim is to obtain a typical reaction to conditions there is no attempt to interfere with normal conditions or modes of dress, so the full complexity of the situation is included in the responses of the subjects.

The underlying assumption of the field survey is that people are able to act as meters of their environment. In effect the subject is used as a comfort meter, not of temperature alone but of all the environmental and social variables simultaneously. Only the effect of time is generally ignored in the analysis. The regression is performed of the comfort vote on the simultaneous environmental conditions: the possibility that the comfort relates more closely to conditions at some previous time, or on some more complex time-series of the environment is not usually taken in to account.

The accepted method of analysis for field surveys is to use statistics. The comfort vote is taken as the dependent variable and the environmental measurements as the independent variables. At the same time people are left to make their choice of clothing, their use of environmental controls, their posture, activity etc. Many of these actions will have been taken in response to the comfort vote. Therefore, the environment is not independent of comfort vote. In addition by their changes of clothing, activity and posture people will also change their own characteristic responses to the environment - again on the basis of the comfort vote. Because of this the results obtained are very specific to the conditions measured. It also means that any formula resulting from the statistical process must be treated with extreme caution, and any such formula should be judged on physical as well as statistical grounds.

Nevertheless the field survey is the key to understanding thermal comfort (Humphreys 1976). Any theoretical model, which does not explain the results of measurements in the field among real people, cannot be reliable for setting standards, which will have meaning among those same real people. Yet in order for the field results to have general applicability there have to be produced general rules from the individual results.

2.6.2 Analytical Approach and Fanger's comfort equation

Almost everybody knows when he or she is cold, but it is difficult to predict an individual's thermal comfort for a particular set of conditions. P.O.Fanger (1972) proposed that the condition for thermal comfort for a given person is that his skin temperature and sweat secretion must lie within narrow limits. Fanger obtained data from climate chamber experiments, in which sweat rate and skin temperature were measured on people at various metabolic rates who considered themselves comfortable. He proposed that the regression line of skin temperature and sweat rate expressed optimal conditions for thermal comfort on metabolic rate from data in these experiments. In this way an expression for optimal thermal comfort can be deduced from the metabolic rate, clothing insulation and environmental conditions. Fanger's basic assumption is that thermal comfort is defined in terms of the physical state of the body rather than that of the environment i.e. what people actually sense is skin temperature and not air temperature.

At steady-state conditions, the rate of heat generation is equal to the rate of heat loss and the energy balance is given by the equation:

$$M-W = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res}) \qquad \text{(Fanger 1972)}$$

Where: M = rate of metabolic energy production W/ m^2

W = rate of mechanical power performed by the body W/ m^2

Q_{sk} = total rate of heat loss from the skin W/ m^2

Q_{res} = total rate of heat loss by respiration W/ m^2

$C + R$ = is the sensible heat loss from the skin W/ m^2

E_{sk} = rate of total evaporative heat loss from the skin W/ m^2

C_{res} = is the rate of convection heat loss from respiration W/ m^2

E_{res} = rate of evaporative heat loss from respiration W/ m^2

In experimental tests of thermal comfort Fanger's equation has proved very successful. The experiments all show that comfort relates to the perceived skin temperature and not to environmental variables or clothing. Experiments also show that for sedentary work and light clothing Ss led to a preferred temperature close to the 25.6°C predicted by Fanger's equation. Also to date no evidence has been found for systematic individual differences in preferred temperatures. There are no effects of age, sex, race, etc.; differences in preferred temperatures often due to clothing differences.

However, Fanger comments that, "*you should use the equation as an assistant to design, not as a master. If you don't know the occupants of the building or what they will be doing there, I believe that you can play around with the variables*" (Bunn 1993).

There is an obvious advantage to having a complete picture of the various thermal factors involved in man's interactions with the environment. Fanger built a model of the physical and physiological conditions governing thermal comfort (1972) which included the Predicted Mean Vote (PMV) and thus formed the basis for the international ISO Standard 7730.

2.6.3 Limitations of the analytical approach

The subjective data on which Fanger's model is based were obtained exclusively from climate chamber studies and in conditions where a steady state had been reached. Fanger has produced a model, which suits environments that can actually be controlled e.g. can help with the design of air-conditioned offices. However, for the environmental designer these characteristics of the Fanger model could pose a number of problems. He must assume that conditions in the building approach those of the steady state in the climate chamber. The limitations of Fanger's model are outlined below:

- The subjective data on which Fanger's model is based were obtained exclusively from climate chamber studies where a steady state had been reached when the subjects had been in constant conditions in the chamber for three hours.
- Prediction of conditions for optimal comfort, PMV or PPD require a knowledge of the clothing insulation and the metabolic rate
- Value of clothing insulation used is obtained by the practitioner from tables in which clothing insulation is listed against descriptions of items or ensembles of clothing. The values of clothing insulation have been determined in experiments using heated manikins.
- Metabolic rate is similarly obtained from tables of activities for which the appropriate metabolic rate is given.

For the environmental designer these characteristics of the Fanger model pose a number of problems.

- He must know what clothing the occupants of the building will wear.
- He must know what activity they will be engaged in and there is an additional problem for buildings where a number of activities are taking place in the same space.
- He must assume that conditions in the building approach those of the steady state in the climate chamber.

All these factors will influence the designer towards a highly serviced building producing closely controlled internal conditions appropriate to some assumed clothing norm and activity. Such considerations render the method very difficult to apply to buildings with less sophisticated mechanical heating and ventilation. The temperature in a free-running building will almost certainly change continually with time, particularly if the inhabitants are able to control it to some extent. So to the difficulty in predicting clothing and metabolic rate is added the problem of applying a steady-state model to an essentially variable situation.

2.6.4 Differences between empirical and analytical investigations

An additional problem has been found with the Fanger model. Some recent field surveys have shown the average values of PMV to be quite different from the average comfort vote in such a way as to overestimate the discomfort of the environment. This means that buildings heated according to accepted standards will be overheated, and those cooled will be overcooled. The evidence for this effect is as yet based on fairly slender evidence, but it is sufficient to cast serious doubts on the reliability of this method, which is, after all, currently used by the heating and ventilation industry internationally to set indoor temperatures.

Due to different results that are obtained in field studies and those predicted by the use of rationally derived equations resulting from climate chambers experiments there has been an argument as to which method provides the most accurate results.

As Humphreys states " field studies are conducted more like a survey accompanied by measurements", and not like an experiment. In most cases they are conducted as subjects go about normally and usually there is no attempt to control the environmental conditions (Humphreys 1976). There have been some cases, however, that some conditions have been altered in order to get a variety of responses for analysis. The measurements taken have varied from just the temperature alone to all the 6 factors affecting thermal comfort.

Fanger, reported by Bunn (1993) argues that the difference in results arises from "poor data input". He comments that " to make a fair comparison, it is essential that all four environmental factors are properly measured and that a careful estimation is made of the activity and clothing".

On the other hand, Cena (1998) argues that, "the more the natural the settings in which a survey is conducted the more applicable the results". Field studies include other parameters that in many cases are adaptation oriented and take into consideration culture (attitude and expectations) (Oseland 1992).

To conclude, these differences can to some extend be explained by the fact that people involved in experiments in climatic chambers will behave differently from those in their naturally set environment. Their expectations are different and consequently their behaviour will be different as well as the results. The main argument arising is whether it is practical to compare results from the theories based on steady state assumptions to real life situations where there is a great possibility for the occurrence of transient conditions.

However, it must be stated that Fanger's work does allow some, maybe simplistic, design techniques to be developed.

2.7 The Adaptive Approach

2.7.1 The Adaptive Mechanism

The generic term "adaptation" might broadly be interpreted as the gradual diminution of the organism's response to repeated environmental stimulation and includes all processes which building occupants undergo in order to improve the "fit" of the indoor climate to their personal or collective requirements (Brager 1998).

The human body maintains thermal equilibrium with its environment by means of physiological thermoregulation (sweating, shivering etc). Beyond these automatic processes, there is a suite of responses, which enable building occupants to adapt to indoor and outdoor climates by means of *behavioural* adjustments (personal, environmental, technological or cultural, *etc*), *physiological* adaptations (genetic adaptation or acclimatization), and *psychological* adjustments (habituation or expectation) (Clark 1985).

An alternative to conventional comfort theory accept the concept that people play an active role in creating their own thermal preferences through the way they interact with the environment, or modify their own behaviour, or gradually adapt their expectations to match the thermal environment (Brager 1998).

Having no direct control over the environment can increase the likelihood of dissatisfaction and then discomfort. Most actions are limited in how far they can be successful, taking off a garment, for instance, can only compensate for a limited change in temperature. Discomfort will arise where temperatures:

- Change too fast for adaptation to take place
- Are outside normally accepted limits
- Are unexpected
- Are outside individual control

Brager and De Dear in a literature review of thermal adaptation in the built environment (1998), concludes that the slower physiological process of acclimatization appears not to be so relevant to thermal adaptation in the relatively moderate conditions found in buildings, whereas behavioural adjustment and expectation have a much greater influence.

2.7.2 Setting Comfort standards using the adaptive model

The "comfort temperature" is defined as the temperature at which there is the least probability of discomfort, or at which satisfaction with the environment is most likely. The value of the comfort temperature will vary at the very least with climate and season. Humphreys (1981) found that the best outdoor temperature predictor for the comfort temperature was the mean of the monthly mean minimum and the monthly mean maximum temperatures.

In a building that is not free running the comfort temperature is decided by social and economic factors rather than only by climatic ones. These variations occur not just between different populations, but also within the same population between economic or social groups. The neutral temperature is not the only temperature which people can find comfortable. Clearly there are allowable variations around it, which will not cause discomfort. The amount of variation allowable will be time-dependent. This is because the longer people have to adapt the further they can change without significantly increased discomfort. Another factor that needs clarification is the variability of temperature (and other factors) within a room. A model that seeks to explain thermal comfort needs to take in to account the variations in conditions within a space, and the constraints on the ability of the occupants to make use of this variability. In conditions where people move around, like in a transitional space, such variability may be a key factor in user satisfaction.

2.8 The Comfort Zone

According to Macfarlane (1978) there are three methods of determining zones of comfort- by questionnaires, by observation of behaviour or by measurement of physiological changes such as mean skin temperature or sweating.

With these methods several thermal comfort standards have been established (ASHRAE 1992), (ISO 7730 1995), (Jokl 1987). These standards specify environmental parameter ranges i.e. comfort zones. The thermal comfort zone is defined as "the zone where no feelings of discomfort occur" (Olgyay 1992). This is a zone where the factors affecting thermal comfort combine to give satisfaction to the people. It is usually taken that at least 80% of the population should be in comfort in the thermal comfort zone. It is considered to be an "acceptability zone" i.e. the zone which 80% of the people will find thermally acceptable. The zone has no precise limits and will vary with individuals, different clothing levels and activities. However, for practical purposes it is usually shown to have limits. For example, ISO (1995) recommends for light, mainly sedentary activity during winter conditions (heating period): "The operative temperature shall be between 20 and 24^0C (i.e. 22 ± 2^0C)"; and during summer conditions (cooling period): "The operative temperature shall be between 23^0C and 26^0C (i.e. 24.5^0C ± 1.5^0C)".

Because of the thermal interaction between building structure, occupancy, climate and HVAC system, pure steady-state conditions are rarely encountered in practice.

According to Hensen (1990) temperature is the most important environmental parameter with respect to thermal comfort, so this study focused mainly on the effects of changes in temperature. According to Macfarlane (1978), the use of dry bulb temperature is a satisfactory index and only in the humid tropics would humidity significantly affect the comfort rating of air temperature.

The general theoretical knowledge concerning thermal comfort in transient conditions is still limited. At present, results of thermal comfort experiments seem to be the only source of information on thermal acceptability in changing environmental conditions (Hensen 1990).

Provided operative temperature is inside the comfort zone, humidity fluctuations, when relative humidity is in the range from 20% to 70%, do not seem to have an appreciable effect. Regarding changing air velocity, no references were found except those dealing with the effect of increased draught complaints when air turbulence is higher (Hensen 1990).

2.8.1 International Thermal Comfort Standards and Recommendations

The American Society of Heating, Refrigerating and Air Conditioning Engineers in the USA, has devised a comfort chart based on the operative temperature and humidity for people clothed in typical winter and summer clothing, engaged in light or sedentary activity (<1,2 met) (ASHRAE 1985).

The Commission of the European Communities in the European Passive Solar Handbook introduces comfort diagrams that show the optimum operative temperature as a function of activity and clothing. The diagram also indicates the comfort ranges around the optimal temperature (the relative humidity is 50%) within which 80% or more of the occupants are expected to find the thermal conditions acceptable (Goulding 1992).

A consideration of the data, the circumstances under which they were obtained and of current practice in the UK, Europe and USA leads to the suggestion that a majority of people in sedentary occupation will neither be warm nor cool in winter in rooms where the dry resultant temperature is between 19^0C and 20^0C, when relative humidity is between 40% and 70% and the air speed is less than 0.1m/sec and for the summer 20^0C to 22^0C (CIBSE 1986). In transient conditions and for the above humidity levels and air speed, the resultant temperature for winter is 16^0C to 18^0C and for summer rises to 23^0C.

All the above thermal comfort zones assume sedentary or light activity (0.5–1.2 met) for occupants, indoor winter or summer clothing (0.5-1.0 clo), air velocity lower than 0.2 m/sec (still air) and perfect level of acclimatization. These assumptions closely apply to the thermal environment to which this study refers.

2.8.2 Thermal Comfort Zone for Greece

In Greece, the only recommendations regarding thermal comfort concern the design air temperature during the heating period, embodied in the Thermal Building Regulations (Greek Thermal Regulations, 1979).

Kolokotroni, in a study in 1989 suggested a thermal comfort zone for Greece, shown in Figure 2.50. The graph also shows the mean daily max and min temperatures and RHs for 39 meteorological stations in Greece. The zone includes temperatures between 19^0C and 26^0C with Relative Humidity 30%-80% and 60%-80% respectively.

As it can be seen from the Chart, very rarely the external climate lies within the limits of the thermal comfort zone.

Avoidance of overheating during the warm period is a major concern in for designers in Greece. However, thermal comfort in indoor spaces can be achieved using appropriate architectural design principles, together with heat removal techniques, and auxiliary cooling equipment.

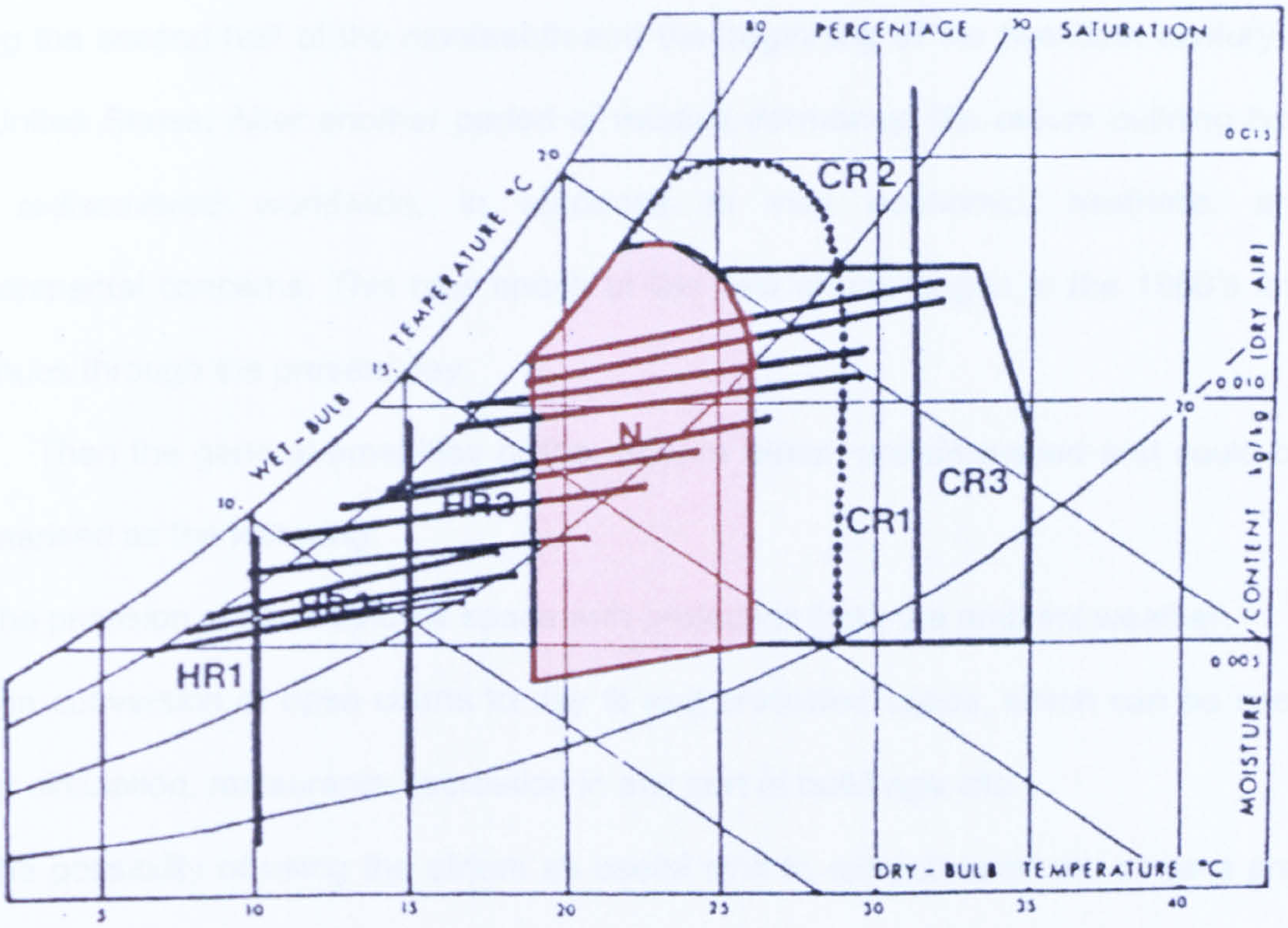


Figure 2. 50:The comfort zone for Greece as suggested from Kolokotroni

The following paragraphs focus on the thermal comfort survey conducted in an atrium building in Greece, and the analysis and discussion of the results.

2.9 Conclusions

This chapter has concentrated on background information related to the research content: the atrium building and thermal comfort.

The first part has been an exploration of the evolution of the atrium building throughout the course of architectural history. The origins of the concept were in the Greek and Roman houses of antiquity. In spirit, the concept was evidenced in the many courtyards built before the end of the eighteenth century. The first epoch of the atrium as intended today, took place in Europe during the first half of the nineteenth century, when the development of iron and glass technology permitted the covering of large courtyard spaces and construction of winter gardens. This development was continued during the second half of the nineteenth and the beginning of the twentieth century in the United States. After another period of relative dormancy, the atrium building type was rediscovered worldwide, in response to vital economic, aesthetic, and environmental concerns. This new epoch of the new atrium began in the 1960's and continues through the present day.

Then the general amenities of the modern atrium are discussed and could be summarised as the following:

- The provision of semi-outdoor space with protection from the ambient weather.
- The conversion of open courts to day lit and protected space, which can be used for circulation, restaurants, recreation in any sort of buildings, etc.
- The possibility of using the atrium as useful sink to extract warm air, or as a pre-heater for ventilation air.
- The reduction of heat loss from building surfaces that would otherwise be exposed to winter weather.
- The enhanced use of daylighting for the majority of the year so that less electric lighting is required during office hours.
- The provision of links, both within one or more buildings and between streets.

All the above attributes, especially the energy potential, are explored in a specific climatic context through case studies visited. The microclimate created in each of these atrium spaces was observed. Furthermore, it results from particular window or skylights orientations, wind exposures, and shading devices. In short, the design of a buffer zone is made more complicated than a fully conditioned building interior by the variety of climatic conditions to which it is exposed.

The general notion claims that an atrium can contribute to passive heating, can be useful in overall ventilation and cooling strategy, and always makes daylight more available to the spaces surrounding it. Most atrium buildings, including those visited in Greece, are thermally heavy (high internal heat gains) and used during the hottest part of the day, making cooling a very important concern. Cooling requires a higher level of energy expenditure per degree of temperature increase.

The second part of the chapter gave background information on the topic of thermal comfort, the thermal comfort parameters, the thermal comfort standards and the comfort zone.

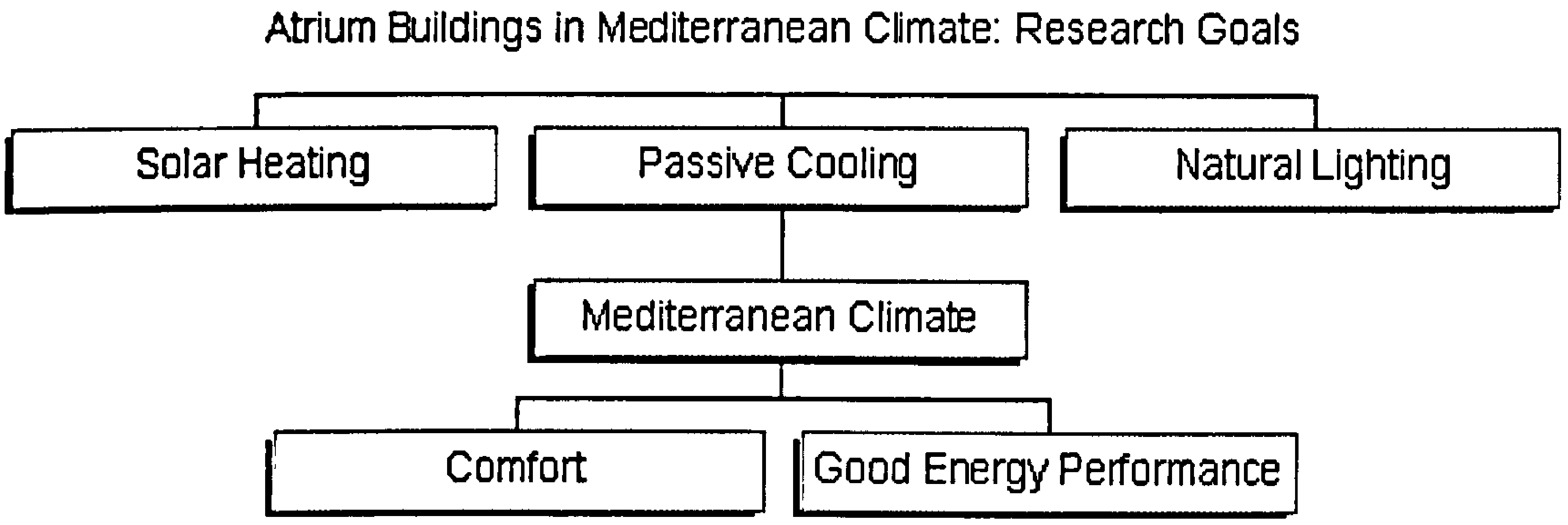


Figure 2. 51: Diagrammatic approach of the research problem

The aim of the research is shaped as in the diagram in Figure 2.51; to explore the capability of utilizing atrium buildings for solar heating, passive cooling and natural lighting for potential energy saving and at the same time achieving a thermally comfortable environment. And since there is a specific climatic context for the research, it was essential, before anything else, to analyse the local climate and explore possible design strategies applicable in that climatic context. In the next chapter there is a definition of climatic responsive design, analysis of the Mediterranean climate, and in more detail of Greece, and a layout of passive solar design strategies for the climate of the city of the case study with the aid of Building Bioclimatic Charts.

CHAPTER 3

CLIMATIC DESIGN OF BUILDINGS IN THE MEDITERRANEAN ZONE

3.1 Introduction

The amount of energy use in a building is a direct result of the climate, the building's use and form, and for this reason it's their elements varied in the parametric analysis. The climatic context is one of the most important factors in building energy efficiency. Devoid of the knowledge of temperature, solar radiation, wind velocity, etc., it is not possible to design a building that is energy efficient without being wasteful of resources. The basic principle of building climatic design focuses on building's response to natural environment and how to gain maximum benefit from the local climatic conditions. In other words, the purpose of climatic design is to maintain or minimise the energy cost of providing thermal comfort conditions within building interiors (Watson 1983). Therefore, it is required to have an understanding of the climatic properties, and this can be developed through analysis of the local weather data.

Additionally, the accuracy of the results obtained from dynamic thermal simulation programmes depends largely on the climatic data input. In most cases, hourly climatic data are required for certain climatic elements. Therefore, thorough climatic analysis is considered essential for this research and a considerable amount of data retrieved will be used later in the dynamic thermal simulation programme.

This chapter is divided in two parts. The first part contains a definition of climate, a quotation and analysis of climate and the use of psychrometric charts for climatic responsive design. The second part focuses on the analysis of the

Mediterranean climate, with reference to Greece, the application of climatic zones and a detailed analysis of the case study climate.

3.2 Climatic Design of Buildings

3.2.1 Climate Definition & Classification

Sun, land and water interact in complicated ways throughout each day and throughout the year; the result is what is commonly referred to as "weather". For a more precise definition, "*weather*"[1] is the set of atmospheric conditions prevailing at a given place and time. These interactions produce daily as well as seasonal temperature, humidity, and wind patterns that can vary substantially between locations in close geographic proximity.

"*Climate*"[1] can be defined as the integration in time of weather conditions, characteristics of a certain geographical location. At the global level, climates are formed by the differential solar heat input and the uniform heat emission over the earth's surface. Weather is on the day to day basis, of sunshine, temperature, precipitation (e.g. rain or snow) and atmospheric pressure. Or the state of the atmosphere with respect to cold, heat, moisture, etc.

Many different systems of climate classification are in use for different purposes, one of which is shown in Figure 3.1. Climatic zones such as tropical, arid, temperate and cool are commonly found for representing climatic conditions. For the purposes of building design a simple system based on the nature of the thermal problem in the particular location is often used:

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[1] Collins Cobuild English Language Dictionary, University of Birmingham, Harper Collins Publisher, 1987

- **Cold climates**, where the main problem is the lack of heat (under heating), or excessive heat dissipation for all or most parts of the year.
- **Temperate climates**, where there is a seasonal variation between under heating and overheating, but neither is very severe.
- **Hot-dry (arid) climates**, where the main problem is overheating, but the air is dry, so the evaporative cooling mechanism of the body is not restricted. There is usually a large diurnal (day - night) temperature variation.
- **Warm-humid climates**, where the overheating is not as great as in hot-dry areas, but it is aggravated by very high humidities, restricting the evaporation potential. The diurnal temperature variation is small.

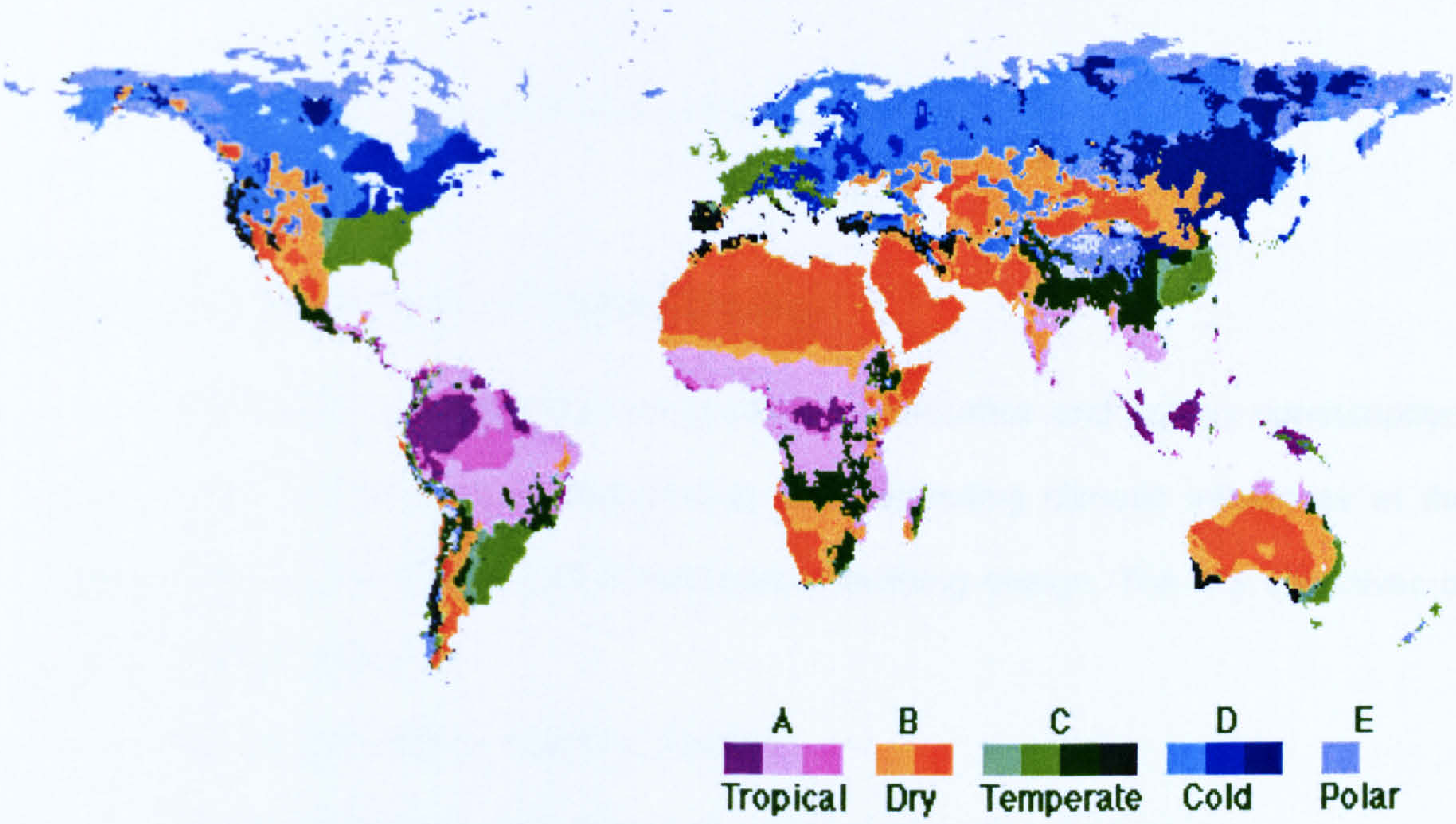


Figure 3. 1: Koeppen's World Climate classification

The general climate (*macroclimate*) is influenced by topography, vegetation and nature of the environment on a regional scale (*mesoclimate*), or at a local level, within the site itself (*microclimate*). Figure 3.2 shows the climate classification on a Psychrometric Chart, the application of which, will be discussed further in the chapter.

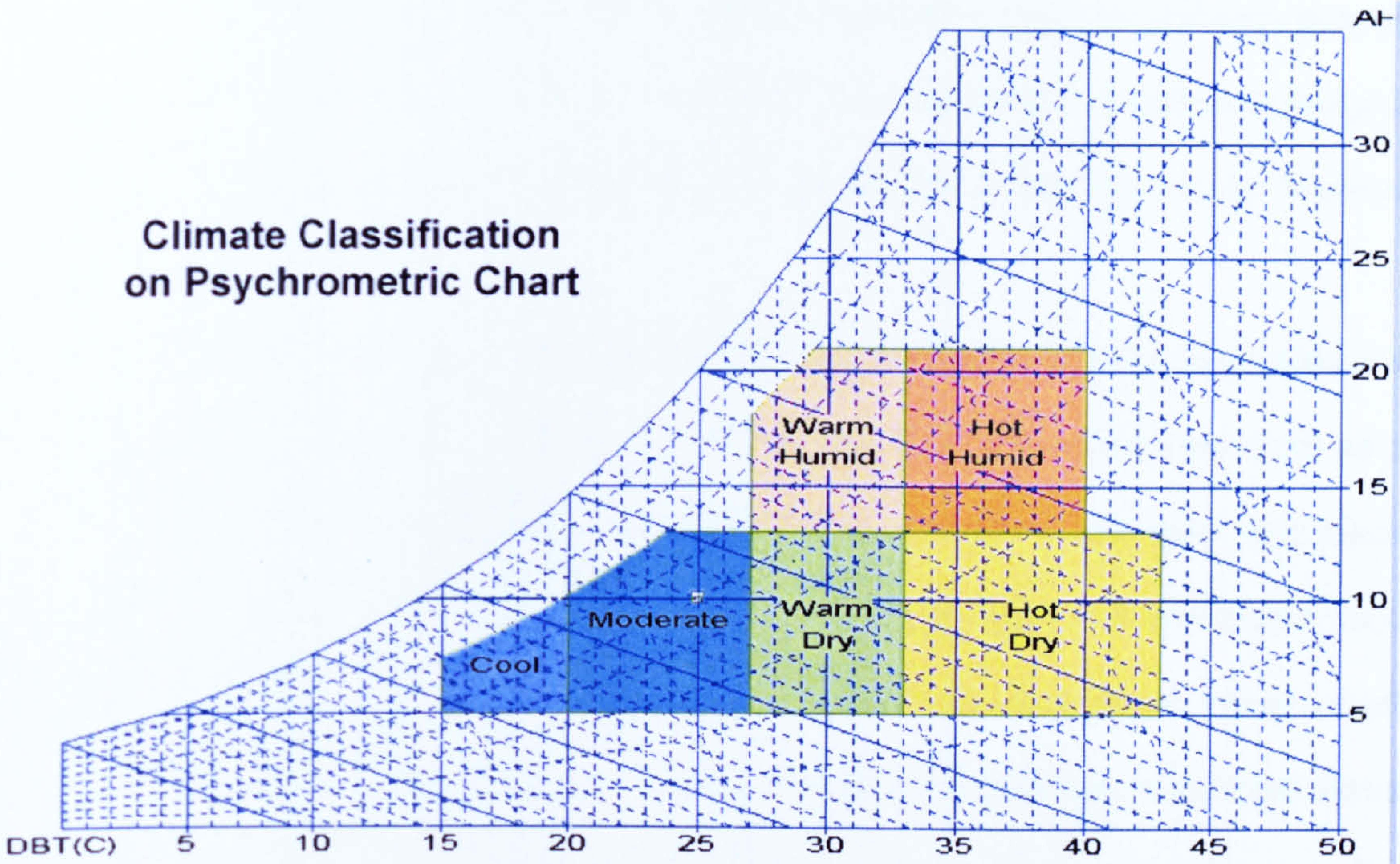


Figure 3. 2: The climate classification on a Psychrometric Chart

3.2.2 Importance of Climatic Design

Climate has a major effect on building performance and energy consumption. The process of identifying, understanding and controlling climatic influences at the building site is perhaps the most critical part of building design. The key objectives of climatic design include:

- Reduction of energy cost of a building;
- Use of "natural energy" instead of mechanical system and power;
- Provision of comfortable and healthy environment for people.

Therefore, climate-responsive design is a strategy that seeks to take advantage of the positive climate phenomena of a particular location, while minimizing the effects of attributes that may impair comfort or increase energy requirements.

To gain a better understanding of this concept, it is worthwhile recognizing certain events that influenced current architectural and urban design practices. Before refrigerated air conditioning was available, climate-responsiveness was an essential building feature because there was no other reasonable way to maintain acceptable temperatures within the building. Architects and engineers employed imaginative schemes to bring daylight and ventilation into all parts of a building in order to provide a comfortable environment.

With the advent of air conditioning, it was no longer essential to provide natural ventilation and daylight in buildings. Therefore, the ability to extract heat from all parts of a building allowed architects and engineers to use as much glass and electrical lighting as they pleased. In addition, building shapes that were once favoured because they provided access to natural light and ventilation were dropped in favour of others that maximized usable footage. As a result, many new buildings resembled immense glass boxes, devoid of any form of articulation to provide shade from the sun. Before the early 1970s, energy prices were low and therefore did not present a significant portion of a building's operating budget. Later, continuously increasing energy prices and the prospect of limited energy resources, climate change and world-wide environmental concerns has led many designers to rediscover means and methods of creating a building that exists in concert with, rather than in opposition to, its environment.

Designers who strive to develop comfortable, low-energy buildings pursue the benefits of climate-responsive design considering the following five basic concepts:

1. Understand climate zones and microclimates;
2. Understand the basic physiology of human thermal comfort;
3. Control the sun effect to reduce heating loads and enhance visual comfort;
4. Use thermal mass to improve comfort and efficiency;
5. Select space-conditioning strategies that are climate responsive

The first of the above concepts is the focal point in this chapter and in the following paragraphs it will be analysed in detail, mainly by describing the climatic elements, the sources of climatic data and the way to use them as an input in simulation programmes. The physiology of thermal comfort and the impact of climate are discussed through the analysis of the psychrometric charts. The last three concepts are analysed in context with the local climate.

3.2.3 Climatic Data

3.2.3.1 Climatic Elements

The main climatic elements, regularly measured by meteorological stations and used as input data in the current research are:

- **Temperature** - dry-bulb temperature.
- **Humidity** - expressed as relative or absolute humidity. The web-bulb temperature or dew-point temperature may be stated, from which the humidity can be deduced.
- **Air movement** - both wind speed and direction are indicated.
- **Precipitation** - the total amount of rain, hail, snow, dew, measured in rain gauges and expressed in mm per unit time (day, month, year).
- **Cloud cover** - based on visual observation and expressed as a fraction of the sky hemisphere (tenths, or 'octal' = eights) covered by clouds.
- **Sunshine duration** - the period of clear sunshine (when a sharp shadow is cast), measured by a sunshine recorder, which burns a trace on a paper strip, expressed as hours per day or month.
- **Solar radiation** - measured by a pyranometer on an unobstructed horizontal surface and recorded either as the continuously varying irradiance (W/m^2), or through an electronic integrator as irradiance over the hour or day.

As it will be discussed in a further chapter, the four environmental variables directly affecting thermal comfort are *temperature, humidity, solar radiation and air movement*; therefore these are the five most important constituents of climate for the purposes of building design (Table 3.1).

Table 3. 1: ***Common climatic elements for building design***

Temperature:	-Monthly mean of daily max (deg^{0}C) -Monthly mean of daily min (deg^{0}C) -Standard deviation of distribution
Humidity:	-Early morning relative humidity (in%) -Early afternoon relative humidity (in %)
Solar radiation:	-Monthly mean daily total (in MJ/m^2 or Wh/m^2)
Wind:	- Prevailing wind speed (m/s) and direction
Rainfall:	- Monthly total (in mm)

3.2.3.2 Sources of Climatic Data

The *raw weather data* from the meteorological station are usually analysed and presented in tabular and/or in graph form. Outdoor design conditions, which are determined from the statistical analysis of climatic data over the long term (say, 30 years), will offer a summary of weather information for a particular location. To study year-round and part-load building performance, annual weather data will be required and they may be given as data, simplified hourly data or full hourly data.

In architectural design, *climatic graphs and charts* are very useful for climate analysis since they can aid to a quick understanding and comparison of data. However, much more detailed data may be required for the purposes of some building thermal and energy simulation programmes, for instance hourly data for a year, (which itself may be a composite construct from many years of actual data). Depending on the time and resources, suitable amount and quality of weather data should be analysed in developing a building design. According to Olgyay (1992), in the study of climatic data it is vital to strike a balance between the two extremes of:

- *Too much detail*; such as hourly temperature for a year, 24 x 365 = 8,760 items, - it would be very difficult to glean any meaning from such mass of numbers and, - if many years are to be considered, it would be an impossible task.

- *Oversimplification*; a statement of the annual mean temperature of -15^{0}C may indicate a range between 10^{0}C and 20^{0}C or between -10^{0}C and +40^{0}C. The greater the simplification, the more detail is concealed.

For the current research, significant amount of climatic data for Greece was collected, in more detail for the climate of Ioannina and Athens where the case study is located. The sources are:

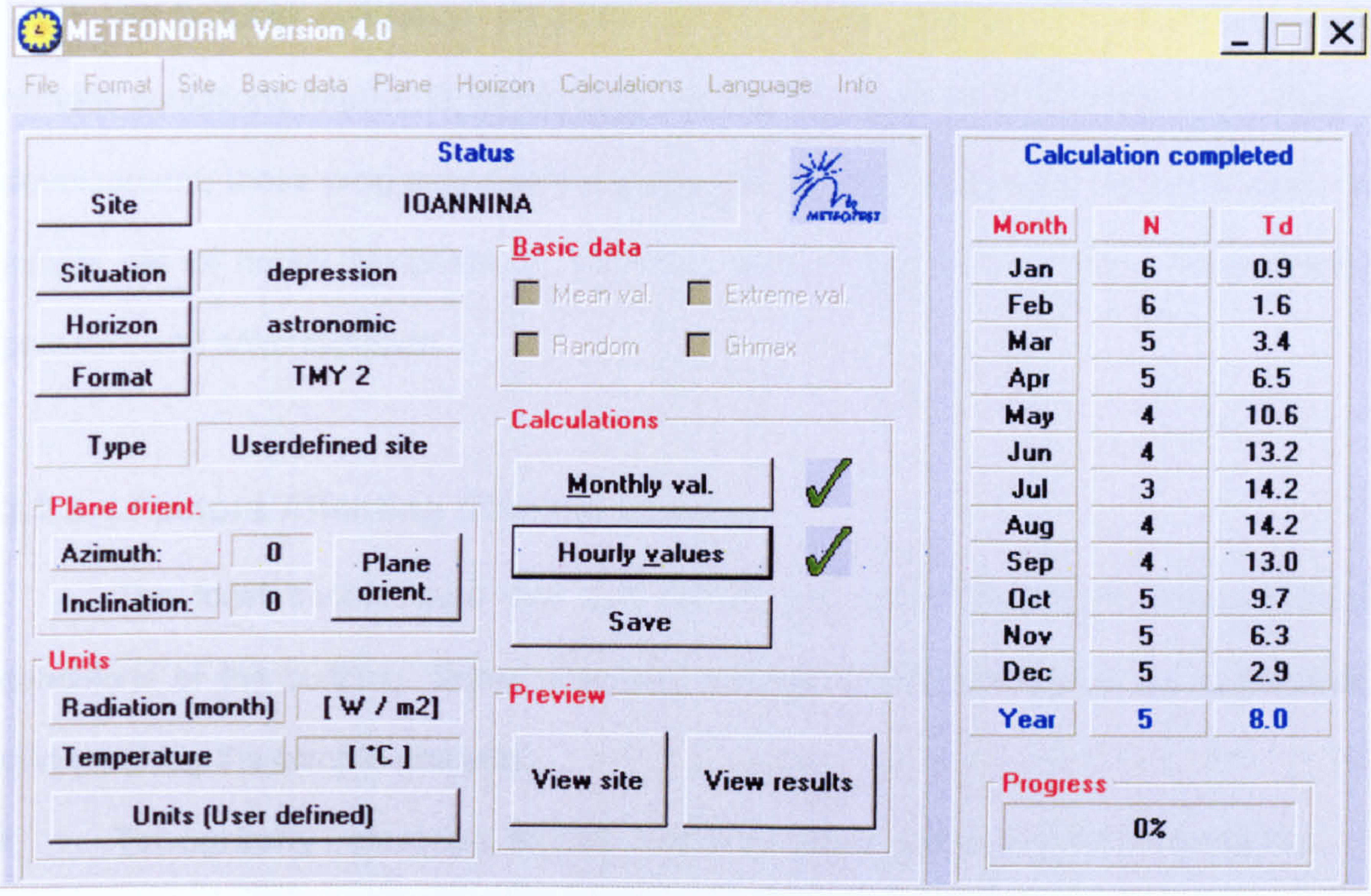
- The Meteorological Station of the School of Physics and Meteorology, University of Ioannina
- The Meteorological Station of the National Technical University of Athens
- The World Weather Guide (Pearce, 1984)
- The European Solar Radiation Atlas (Palz 1995)
- Climatic data personally collected on site
- Climatic data calculated through METEONORM software (Meteotest 2001)

The amount and type of climatic data collected will be described on the context of each chapter.

3.2.3.2.1 Processing Climatic Data with METEONORM

As stated above, one of the sources of climatic data for the current study was METEONORM. That was based on the need for a very detailed weather file as input for the simulation programme. The other sources of climatic data partially fulfilled the requirements and the use of METEONORM was necessary to cover the missing data. Below there is a description, requirements and accuracy of the data produced.

METEONORM is primarily software for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location. It is based on databases and algorithms coupled according to a predetermined scheme. It requires input about a particular location for which meteorological data are necessary, and delivers data of the desired structure and in the required format.



Site: IOANNINA
Situation: depression
Horizon: astronomic
Format: TMY 2
Type: Userdefined site

Plane orient.
Azimuth: 0
Inclination: 0

Units
Radiation (month): [W / m2]
Temperature: [°C]

Month	N	Td
Jan	6	0.9
Feb	6	1.6
Mar	5	3.4
Apr	5	6.5
May	4	10.6
Jun	4	13.2
Jul	3	14.2
Aug	4	14.2
Sep	4	13.0
Oct	5	9.7
Nov	5	6.3
Dec	5	2.9
Year	5	8.0

Figure 3. 3: The output data from METEONORM software

Owing to the comprehensive framework chosen for the present edition, certain inconsistencies could not be avoided. The error in interpolating the monthly radiation values was 11 %, and for temperature 1.9°C. In general, the hourly model tends to underestimate the total radiation on inclined surfaces. The discrepancy compared to measured values is ± 3% for individual months in summer and +10% in winter. However, since the total radiation in winter is minimal, this has only a small effect on the yearly average, and the error is +2%.

3.2.3.3 Improving the weather information available to simulation programmes

Developers of building simulation tools have been continuously improving their programmes, adding new capabilities over the last thirty years. Time steps of less than an hour are now common and even necessary to properly simulate the complex interactions of building components and systems.

All building simulation programs employ some means of representing local climatic conditions relative to the building models. But even after 30 years of significant development, these programs use the same climate representations as in the past – a simple set of hourly temperature, humidity, wind speed and direction, atmospheric pressure and solar radiation

3.2.3.4 Factors Affecting Climatic Design

The local microclimate and site factors will affect the actual environmental conditions of the building. Some important site-related factors should be considered when making the climate analysis:

- **Topography** - elevation, slopes, hills and valleys, ground surface conditions.
- **Vegetation** - height, mass, silhouette, texture, location, growth patterns.
- **Built forms** - nearby buildings, surface conditions.

Major thermal design factors to be studied include: solar heat gain, conduction heat flow and ventilation heat flow. The design variables in architectural expression that are important will include:

- **Shape** - surface-to-volume ratio, orientation, building height.
- **Building fabric** - materials and construction, thermal insulation, surface qualities, shading.
- **Fenestration** -the size, position and orientation of windows, window glass materials, external and internal shading devices.
- **Ventilation** - air-tightness, outdoors fresh air, cross ventilation and natural ventilation.

3.2.3.5 General Climate Control Strategies

The building envelope is a device through which heat exchange between the interior and exterior environments is controlled. It intercedes with the external climate, creating a new interior microclimate zone (Watson 1983).

According to the existing conditions and the desirable outcome, the fundamental control options (illustrated in Figure 3.3), consist of:

When cold discomfort (under heated) conditions prevail

- Minimise heat loss
- Utilise heat gain from the sun and internal sources

When hot discomfort (over heated) conditions prevail

- Prevent heat gain
- Maximise heat dissipation

Subsequent to climate analysis and building's performance measurements, there will be a detailed exploration of environmental control and design strategies in the parametric study in a following chapter.

			CONDUCTION	CONVECTION	RADIATION	EVAPORATION
CONTROL STRATEGIES	WINTER	PROMOTE GAIN			Promote Solar Gain	
		RESIST LOSS	Minimize Conductive Heat Flow	Minimize External Air Flow Minimize Infiltration		
	SUMMER	RESIST GAIN	Minimize Conductive Heat Flow	Minimize Infiltration	Minimize Solar Gain	
		PROMOTE LOSS	Promote Earth Cooling	Promote Ventilation	Promote Ventilation	Promote Evaporative Cooling
		HEAT SOURCES		Atmosphere	Sun	
		HEAT SINKS	Earth	Atmosphere	Sky	Atmosphere

Figure 3. 4:General climate control strategies (Watson 1983)

3.2.4 Climate Analysis

Different design situations will require different sets of weather data. In the current research, climate analysis carried out at initial design stage will be used primarily for the development of design strategies for thermal comfort predictions as well as for the calculation of cooling and heating requirements of the case study building.

Before embarking on an analysis of the local climate, it was considered essential to view the general features of the Mediterranean climate and the potential for passive design in this specific context. Some of the factors would have to be considered in the early stages, in order to produce a climatically responsive design. Later these are going to be transformed into design strategies, analysed in more detail with the use of psychrometric charts.

3.2.4.1 Building Bioclimatic Charts

Climate data analysis, aimed at formulating building design guidelines, often involves presentation of annual patterns of the main climatic factors affecting human comfort and thermal performance of buildings. This may happen in various forms, such as graphical monthly patterns of the local temperatures, humidity, wind speed, radiation, etc., as well as bioclimatic charts (Givoni 1976) and (Olgyay 1992).

One effective way to gain understanding of the prevailing temperature conditions for a region is to consult bioclimatic charts for a specific project location. Bioclimatic charts facilitate the analysis of the climatic characteristics of a given location from the viewpoint of human comfort, as they present the concurrent combination of temperature and humidity at any given time. They can also specify building design guidelines to maximize indoor comfort conditions when the building's interior is not mechanically conditioned. All such charts are structured around, and refer to, the "comfort zone". The "comfort zone", as it will be defined in a following chapter, is the range of climatic conditions within which the majority of people would not feel thermal discomfort, either of heat or of cold.

Indoor climate in unconditioned buildings responds to the variations of outdoor climate and the inhabitants usually experience a wider diurnal climatic range than in environmentally controlled buildings. This difference between the acceptable conditions in environmentally controlled and non-conditioned buildings should also be reflected in the chart specifying boundaries of acceptable indoor climate for unconditioned buildings and in the boundaries of applicability of various building design strategies (Givoni 1992). That is – occupant's verdict to internal climate is partly governed by the type of space (conditioned or unconditioned) and their expectations.

3.2.4.1.1 Olgyay's Chart

The concept of relating coincident temperature and humidity conditions to the climate control needs in building design, was well defined by Olgyay in the early 1950s and since revised (Archard 1987).

The chart has relative humidity in the abscissa and temperature in the ordinate. Comfort ranges for still air conditions, for summer and winter, are plotted on the chart. The temperatures below the lower limit of the comfort range are defined as "under heated" conditions and above it as "overheated" conditions. The ability to extend the summer comfort range to higher temperatures and humidities by shading devices, with increasing wind speeds, and the ability to lower the air temperature by water evaporation, are also plotted on the chart.

The comfort zone boundaries were based on the ASHRAE Standards (ASHRAE 1992), which suggest that between 21.5^{0}C and 25^{0}C, at 50% RH, 80% or more of the occupants would find the environment thermally acceptable (Archard 1987).

Another comfort chart that was developed by Olgyay was the "Timetable of Climatic Needs". In this chart the abscissa marks the months of the year and the ordinate marks the hours of the day. For any given location, the overheated, comfortable and under heated periods, can be determined from the plots of the annual climatic conditions on the Bio-Climatic Chart.

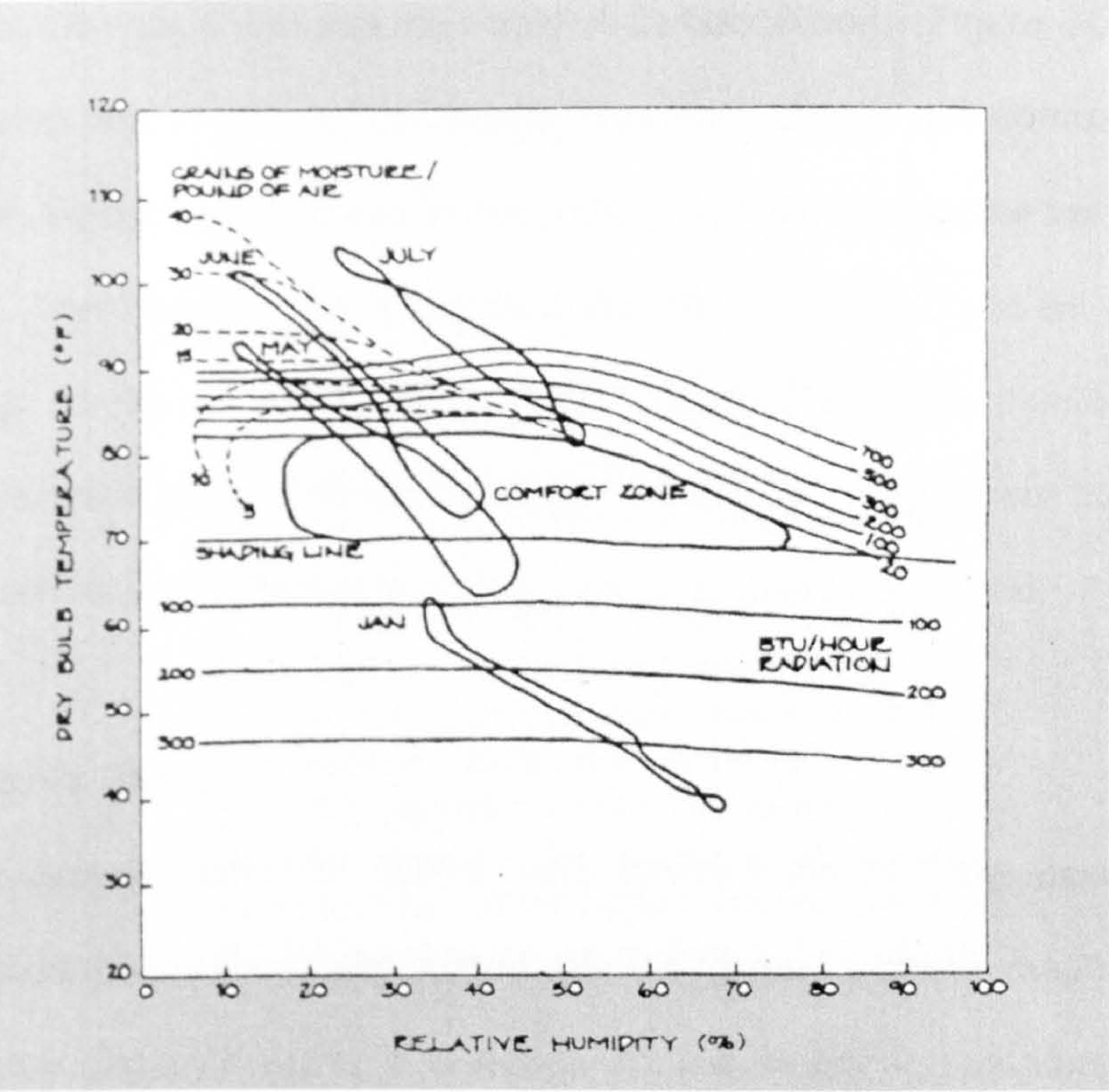


Figure 3. 5.a: Olgyay's charts for Phoenix Arizona; (a) Bio-Climatic Chart

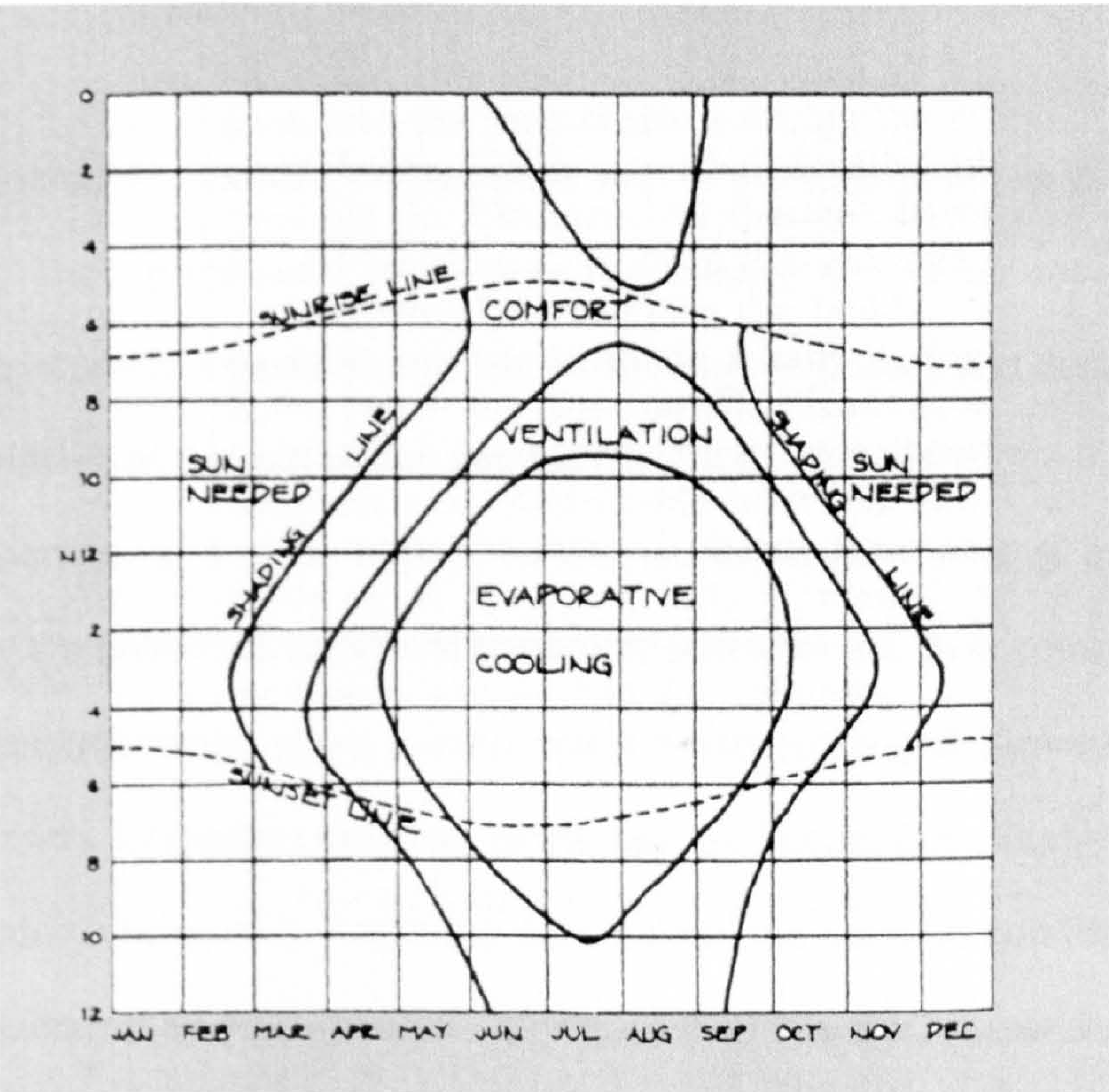


Figure 3. 5.b: Olgyay's charts for Phoenix Arizona; (b) Timetable of climatic needs

The Bio-Climatic Chart and the Table of Climatic Needs (Figure 3.5 a and b) are strictly applicable only to outdoor conditions. However, Olgyay has commented that, in his experience, indoor temperatures in unconditioned buildings can be very close to the outdoor level. Therefore he has suggested that these charts could be used also as guidelines, e.g., for the advisability of ventilation. Givoni (1976) has pointed out that the indoor temperature in unconditioned buildings, especially in high-mass buildings in hot arid regions, can be very different from the outdoor ambient conditions.

3.2.4.1.2 Givoni's Chart

A few decades later, B. Givoni, who devised the Building Bioclimatic Chart (BBC) to address the problems associated with the Olgyay's charts, made an important extension of the Olgyay's work. It is based on the indoor temperature in buildings (expected on the basis of experience or calculations). Graphically, the BBC differs from Olgyay's chart as it is drawn on a conventional psychometric chart, like the ASHRAE chart (1985).

Psychrometry is the study of moist air and of the changes in its conditions. The psychrometric chart graphically represents the interrelation of air temperature and moisture content and is a basic design tool for building engineers and designers. All the terms are explained at the end of the chapter.

The "climate" of a given region, as defined in the beginning of the chapter, is determined by the pattern of variations of several elements and their combinations. The principal climatic elements, when human comfort and building design are concerned, are solar radiation, long-wave radiation to the sky, air temperature, humidity, wind and precipitation (rain, snow, etc). For many applications the extreme conditions and their expected frequency may be of greater importance than the average conditions.

The movement of the state point on the psychrometric chart can represent psychrometric processes, i.e. any changes in the condition of the atmosphere. Common processes include:

- Sensible cooling / sensible heating
- Cooling and dehumidification / heating and humidification
- Humidification / dehumidification
- Evaporative cooling / chemical dehydration

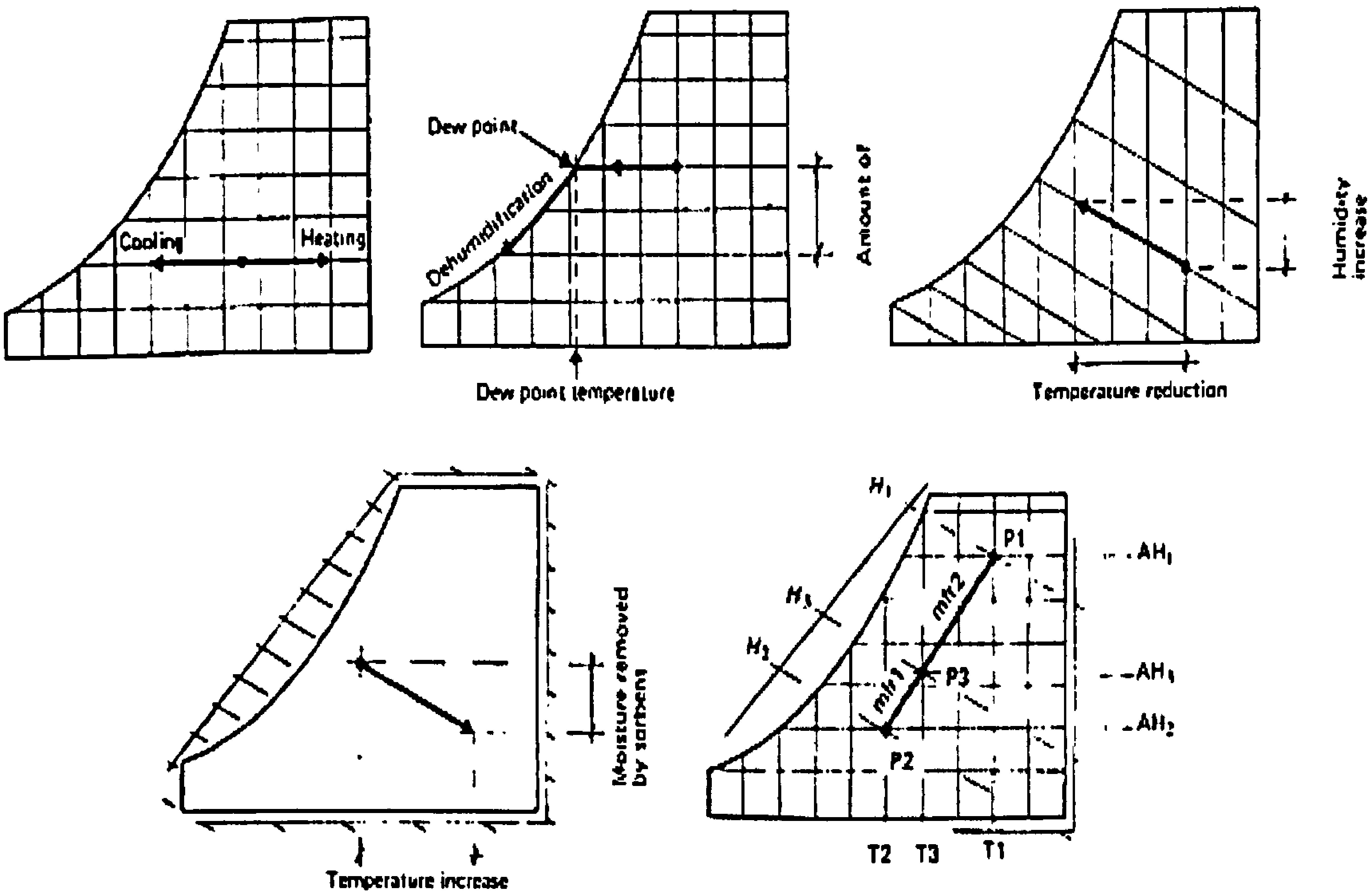


Figure 3. 6: Psychometric processes

Various combinations of temperature and relative humidity that provide acceptable thermal comfort can be plotted on a standard psychrometric chart to define the human "comfort zone". The implication is that space conditions falling within this zone are likely to provide acceptable thermal comfort for most people. However, it is important to note that each person's comfort zone will vary depending upon the individual's amount of clothing, metabolic activity, and other factors. Surprisingly, with the diverse range of climates, living conditions, and cultures around the world, most people would choose to be within the same temperature range when clothed similarly and performing at the same level of activity (ASHRAE 1992). However, regional adaptation does occur and it should be consider, as it may have a significant effect to peoples acceptance of a specific environment.

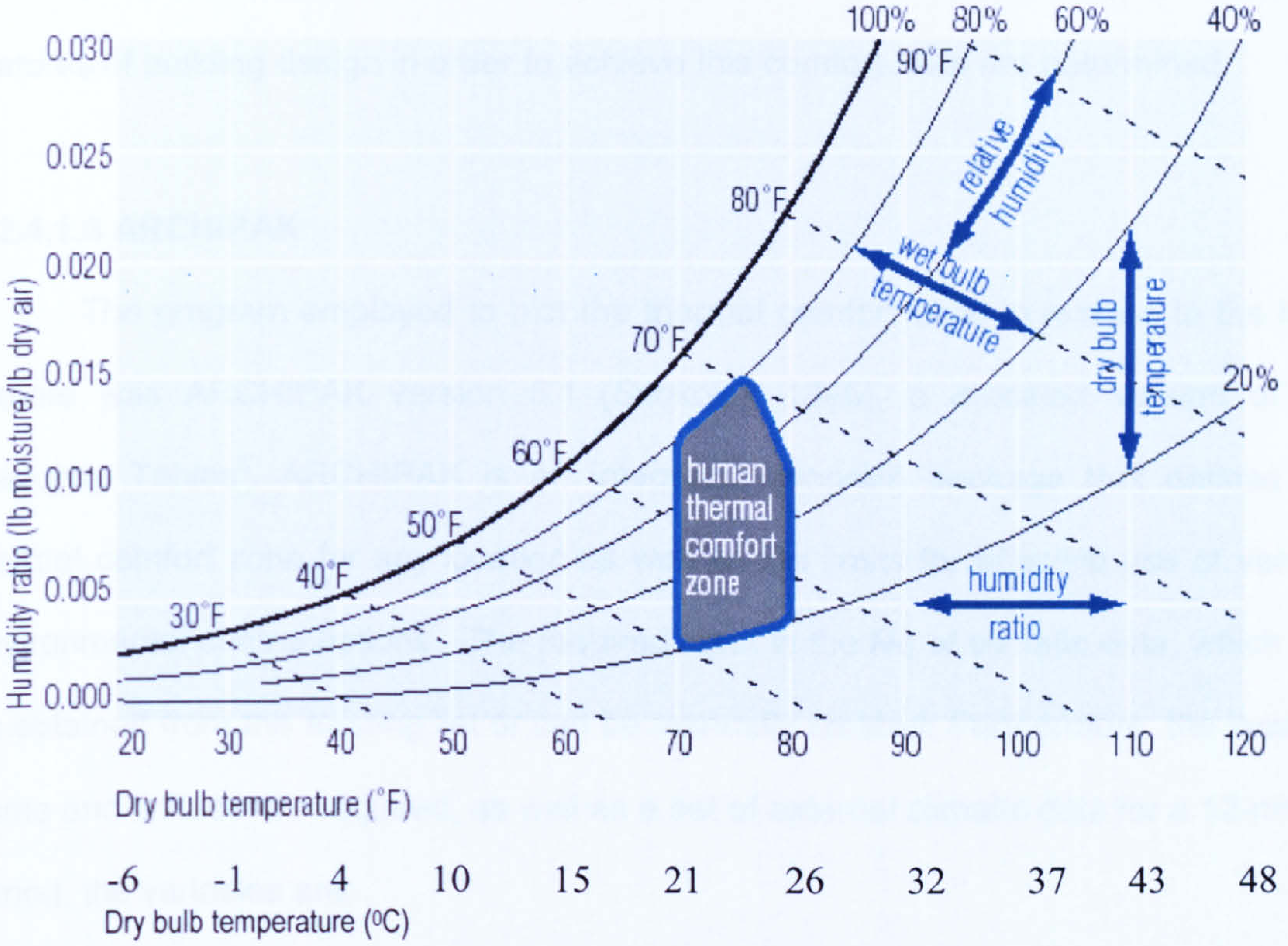


Figure 3. 7: The psychrometric chart is similar to Givoni's BBCC, except for the use of percentage saturation instead of relative humidity

The psychrometric chart shown in Figure 3.7 provides a graphic representation of the full state of air under any condition. It relates temperature on the horizontal scale to moisture on the vertical scale. If the temperature of a given volume of air is decreased to the point at which it can hold no more moisture, it becomes saturated. The corresponding temperature is called the dew point and is shown by a curved line, which gives the chart it distinguishing shape.

Given any point on this graph, a wide range of information about the state of the air can be found. This includes all the major climatic indicators, dry-bulb and wet-bulb temperatures, relative and absolute humidity, vapour pressure, air volume and even enthalpy.

In order to define the limits of this chart, Givoni uses the Index of Thermal Stress (ITS) to evaluate the human requirements for comfort. From this, the necessary features of building design in order to achieve this comfort level are determined.

3.2.4.1.3 ARCHIPAK

The program employed to plot the thermal comfort zone in relation to the local climate was ARCHIPAK version 5.1 (Szokolay 1995), a modified version of the Mahoney Tables[2]. ARCHIPAK is an integrated program package that defines the thermal comfort zone for any location as well as the limits for effective use of various environmental control options. The required input is the file of climatic data, which can be obtained from the existing list or can be manually created. Furthermore, the location name and latitude are required, as well as a set of external climatic data for a 12-month period, the variables are:

Tmax = mean maximum temperature (^{0}C)
SDmax = standard deviation of mean maximum temperatures
Tmin = mean minimum temperature (^{0}C)
SDmin = standard deviation of mean minimum temperatures
RHam = relative humidity for a morning hour (%)
RHpm = relative humidity for an afternoon hour (%)
Rain = monthly total rainfall (mm)
Irad = daily total irradiation, average for the month (Wh/m^{2} day)

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[2] The Mahoney Tables is a passive control analysis system developed by Carl Mahoney and first published by the UN (Koenigsberger et al.1971) and it compares climatic data with empirically established set of comfort limits and translates the results into design recommendations.

The adaptive model of thermal comfort expresses the neutrality temperature as a function of prevailing outdoor temperatures. The Auliciems (ASHRAE 1992) correlation is adopted:

$$\mathbf{Tn = 17.6 + 0.31 \times To.av} \qquad (3.1)$$

Where: To.av is the outdoor mean temperature of the month

(With the provision that $18<Tn<28$)

The range of comfort can be taken as from Tn-2 to Tn+2 ^{0}C

Before the analysis of the building bioclimatic charts for the case study, it was essential to look into the Mediterranean climate, and in more detail the climate of Greece.

3.3 The Mediterranean Climate

As stated before, any research related to climatic responsive design of buildings and thermal comfort requires a thorough study of the climate of a given location.

The following part of the chapter provides a general understanding of the Mediterranean climate. It then focuses on the Greek climate, the classification of climatic zones and the general characteristics of each climatic zone in Greece.

The last part of the chapter focuses on the analysis of the climate of Ioannina, where the case study is located. Furthermore, the application and analysis of bioclimatic charts, provides a valuable insight on the applicable design strategies suitable for the climate of Ioannina, and a discussion of which strategies could be applied in the design of atrium buildings in the specific climatic context.

3.3.1 General Features of the Mediterranean Climate

3.3.1.1 Geographical characteristics

The countries surrounding the trapped Mediterranean basin are characterised by special climatic conditions due to combination of their latitudes and the influence of the sea on the area's weather. Additionally, a significant role is played by the terrain of the northern part of the basin, which consists of high mountains (Figure 3.8). Thus, the climate of the European Mediterranean countries introduces special characteristics, which are also encountered in certain areas of Australia and in California, USA.

The Mediterranean Sea lies within the temperate zone between 30^0 and 46^0 N. Except for a small part of North Africa, the rest of the sea is enclosed by mountains over 3000 metres high. As a result of the topography, the most significant features of the weather consist of mild and wet winters, and relatively hot and dry summers. Furthermore, the transitional season of spring takes place with a number of false starts. On the other hand, autumn is relatively short, ending in early November.

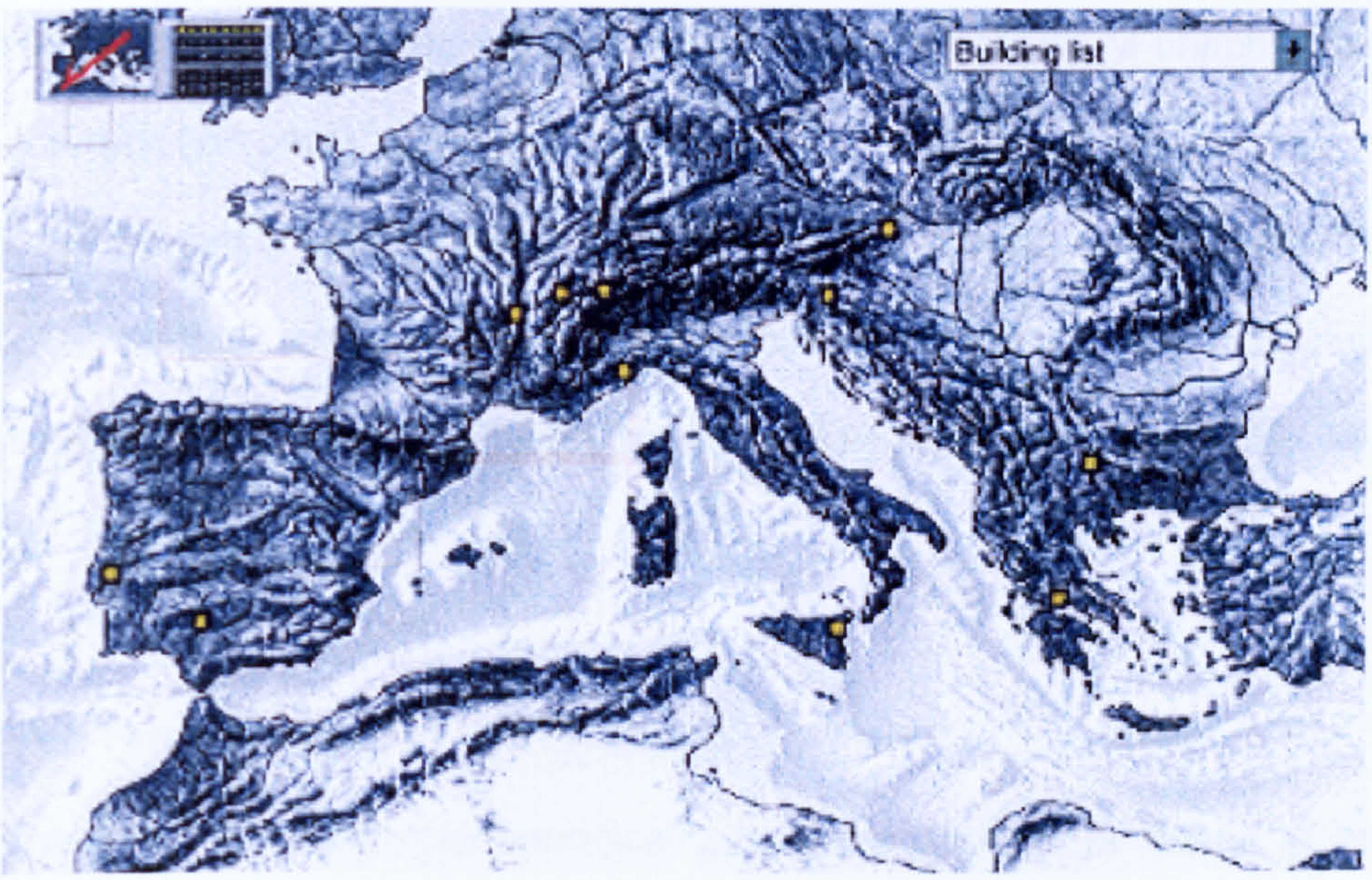

Figure 3. 8: The Mediterranean basin

In the Mediterranean there are mainly two season categories, the warm season and the cool season. Warm season denotes the months from June to September and cool season the months from October to May, although October and May can be regarded as transitional months. Asimakopoulos and Santamouris (1996) have divided the Mediterranean region into four zones according to latitude:

Zone A, $\varphi < 37^0$ N

Zone B, 37^0 N $< \varphi < 40^0$ N

Zone C, 40^0 N $< \varphi < 43^0$ N

Zone D, $\varphi > 43^0$ N

In the following paragraphs four principal climatic elements for building design in the Mediterranean will be looked at: solar radiation, air temperature, humidity and wind.

3.3.1.2 Solar Radiation

It is widely known that all the observed atmospheric processes are the consequences of the solar radiation. The prevailing weather conditions in the Mediterranean basin, combined with the latitude, form conditions of uniform distribution of the solar radiation parameters.

Over the whole Mediterranean zone the annual variation of the global radiation is the same, having a maximum in July and a minimum in December. The percentage of the global radiation during the warm period (June-September) covers the 47-50% of the annual values.

3.3.1.3 Air Temperature

The most important meteorological parameter relevant to issues of buildings' cooling and of human comfort in external and internal environments is the air temperature. In the Mediterranean region, owing to the great longitudinal extent of the surrounding countries (30^0-45^0 N latitude) and to the terrain, there are great contrasts in temperature i.e. cold in winter, hot in the summer.

For cooling purposes, the parameters of greater interest are the mean monthly maximum air temperatures, especially those of the warm season (June-September), which are more directly related to the number of hours per day that the air temperature exceeds the comfort level. These are influenced by local conditions, such as sea breezes or seasonal winds, e.g. Etesian winds in the Aegean Sea.

3.3.1.4 Relative Humidity

The conditions of human comfort do not depend only on the prevailing conditions of air temperature. Significant roles are also played by the prevailing atmospheric humidity and by the wind, which contributed to the modification of evaporation.

The Mediterranean region is characterized by values of relative humidity that, in general, do not create conditions of human discomfort. In addition, unlike other meteorological parameters, the regional distribution of the relative humidity is fairly uniform. The Eastern Mediterranean, in general, has slightly lower values of relative humidity than the other regions.

3.3.1.5 Wind

The wind, with the temperature and the humidity of the air, plays an important role in human comfort in the exterior environment. In addition, proper building design in relation to the prevailing wind directions may contribute to natural cooling of buildings.

The topography of the northern part of the Mediterranean basin, combined with the African deserts and the indented coasts, has as a result a multiform wind field in the Mediterranean. In the central and western Mediterranean it is recorded, more often in summer than winter, low wind speeds, while in the Aegean Sea, the prevalence of the Etesian winds during summer months favours the development of high wind speeds.

3.3.2 The Climate of Greece

The major factors that effect weather in Greece are its many mountains, the amount of direct sunlight received, and the surrounding body of water, the Mediterranean Sea.

3.3.2.1 Greek topography

Greece is famous for its natural beauty, with rugged and mountainous land, sometimes bare, sometimes covered in rich forests. The coastal waters are shallow and penetrate far inland. Thus, Greece's topography is diverse. It also has a wide range of climate types, ranging from the semi-arid, semi-desert of southeastern Crete to the cold, humid continental of Rhodope.

In general, summers are hot and dry whilst winters are wet and cold. The average temperature in the Athens area is 17^0C but this can vary from below freezing in winter to around 40 ^{0}C in the summer.

3.3.2.2 Microclimate in Greece

All of Greece has the same overall climate, and it has hardly changed from ancient times. The macroclimate is called Dry Summer Subtropical, or Mediterranean. This Dry Summer Subtropical means that, summers are long, hot, and dry and it usually extends with little rainfall for three to four months. Winters are short, and mildly wet; there is also pick rainfall during this season. Spring and autumn are the shortest seasons; it either rains or it's hot. Rainfall during summer it's heavy and have short duration.

There are four distinct microclimates (small areas that have the same climate and weather patterns):

1.Lowland seashore

2.Mountain

3.Mountain Plains

4.Northern

1.Lowland seashore: In Greece there is a long line of seashore since the sea surrounds the country. Consequently this microclimate stretches all around the country. Also it is low, not a mountainous area. The temperature in this zone rarely sees big changes, because the water nearby moderates temperature change. This area hardly ever sees frost, or snow; but only rain. Warm temperatures, and sunny skies is the main forecast during the summer. During the winter, mild rains off and on, with mild to warm temperatures. Athens is in this zone.

2. Mountains: This zone also a great part of the Greek area, since Greece is a country full of mountains; even the islands around have mountains. Mountains add new features to the macroclimate; the main one is snow. Some mountain peaks have snow all year round. This wind side of the mountain also sees greatly more rain than other parts of Greece, and experiences higher temperature changes because of wind.

3. Mountain Plains: As the geography suggests, this microclimate is within the mountain peaks. These areas are isolated throughout the country of Greece. They experience more rain, due to their mountain neighbours, but have less extreme cold. Often these areas are protected by winds and major storms, and have a more distinct four-season year.

4. Northern Greece: Being farther north, this area has more seasonal change. It is away from the Mediterranean, which causes greater changes in temperature as well. It is also closer to the Jet Stream (a river of air that directs major storms) that could sometimes experience the affects of storm from the Atlantic Ocean. Overall, this area is generally cooler than the southern parts, because it does not get as much direct sunlight.

3.3.2.3 Building Climatic Regions of Greece

As mentioned before, a crucial part of climatic responsive design is the comprehension of the local climate. That includes a variety of factors that are not always available. Therefore, for convenience of the designer, there have been studies that produced sets of data representative of specific climatic regions, together with design recommendations. Mostly, it is quite difficult to define the exact boundaries between climatic zones or accurately map them.

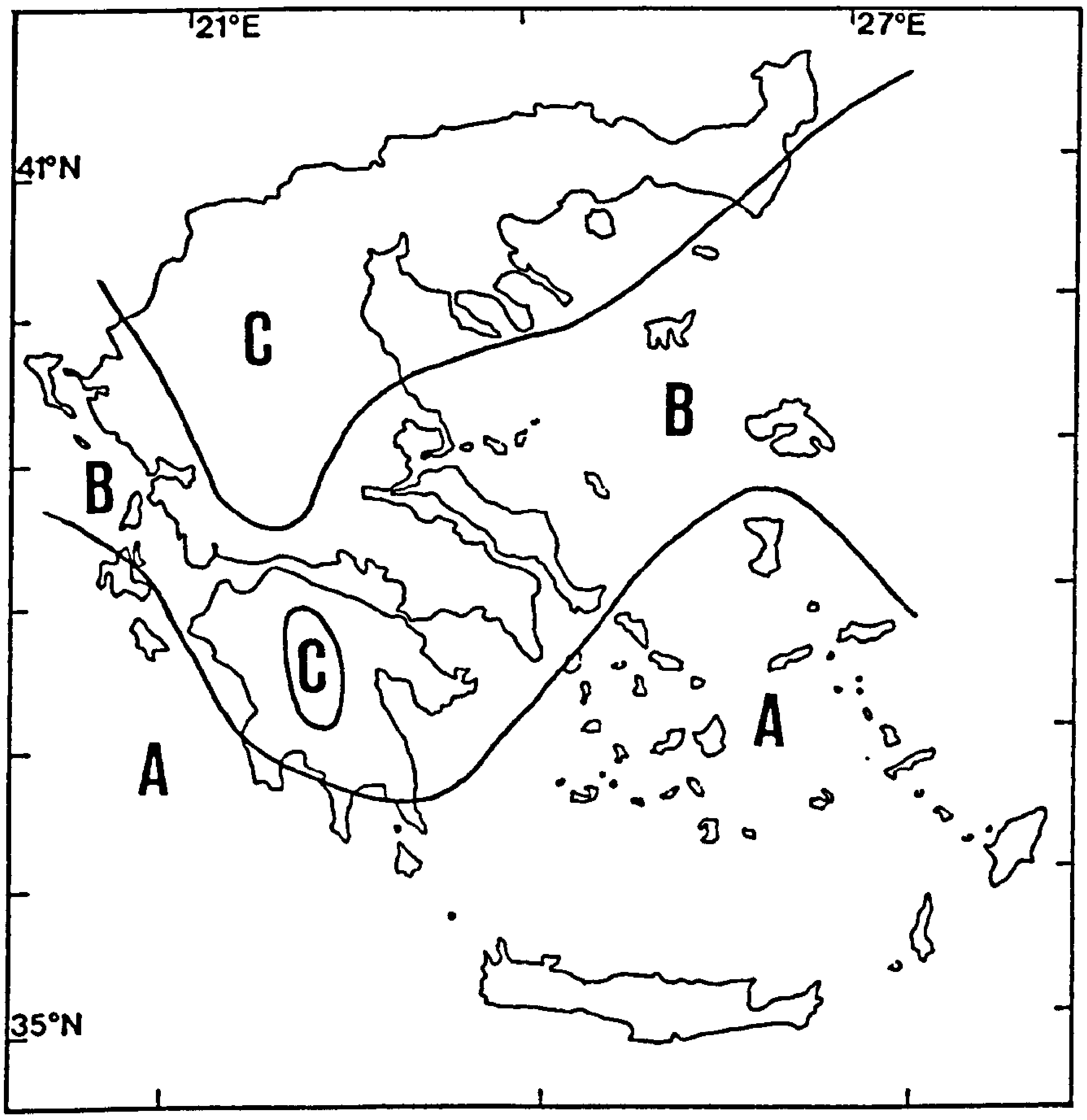

Figure 3. 9:The division of Greece in three climatic zones (C.R.E.S.)

Although Greece has a generally temperate climate, as it was shown in the last paragraph, it is possible to define regions with different climatic conditions. The thermal insulation regulations for Greek buildings, introduced in 1979 (Greek Thermal Regulations), divide the country in three climatic zones, as shown in Figure 3.9, based on the duration of the heating period. However, mean monthly temperature values in each zone are not available. Therefore, indicative sites, from each zone, were selected. The mean monthly values for each site were collected to calculate the average temperatures by zone. The average temperatures for the three climatic zones are shown in Figure 3.10.

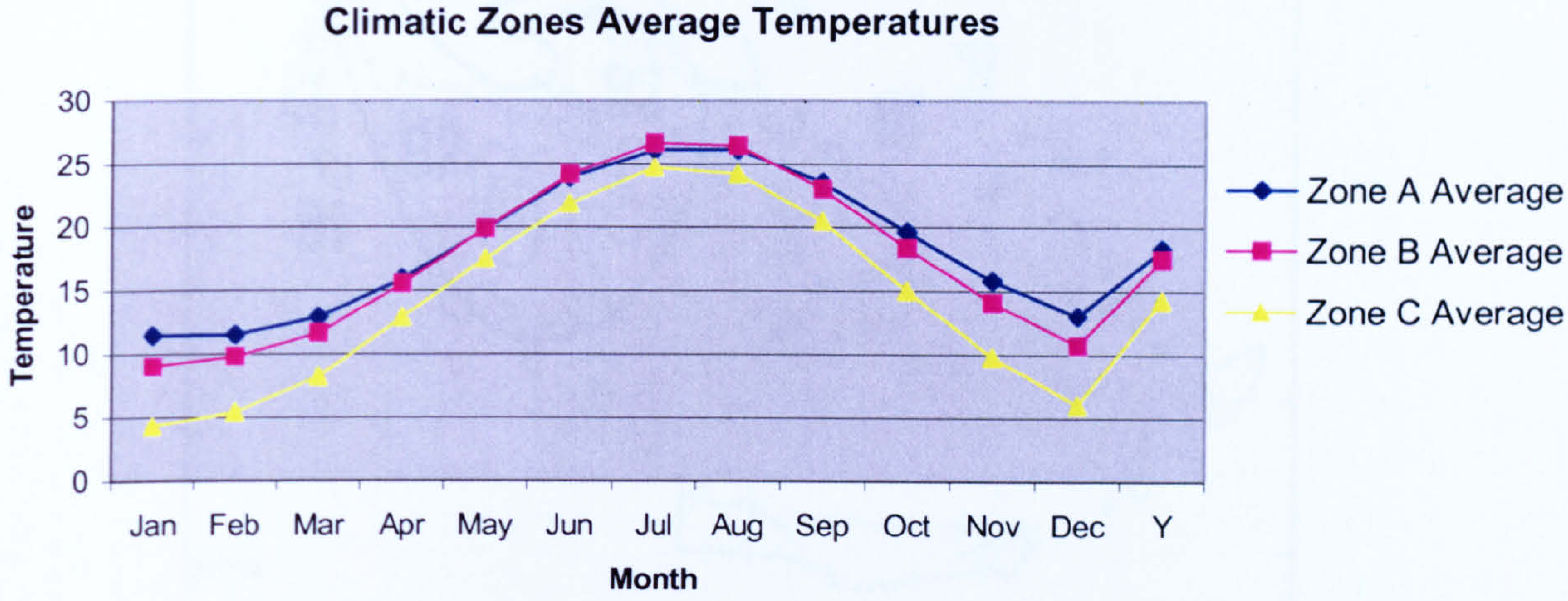

Figure 3. 10: Average temperatures for the three climatic zones of Greece (C.R.E.S.)

According to Kolokotroni (1988), the application of this division is limited to the underheated period of the year. Furthermore, it does not consider other environmental variables such as levels of humidity, wind speed and wind direction, precipitation and most importantly solar radiation, which certainly influence bioclimatic building design.

In the same study, M. Kolokotroni and A. N. Young[3] investigated the available climatic data for Greece, and from the analysis they produced a new division of the country into a number of climatic regions, the Building Climatic Regions (Figure 3.11).

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[3] The predictions were made using the Building Bioclimatic Chart devised by Givoni

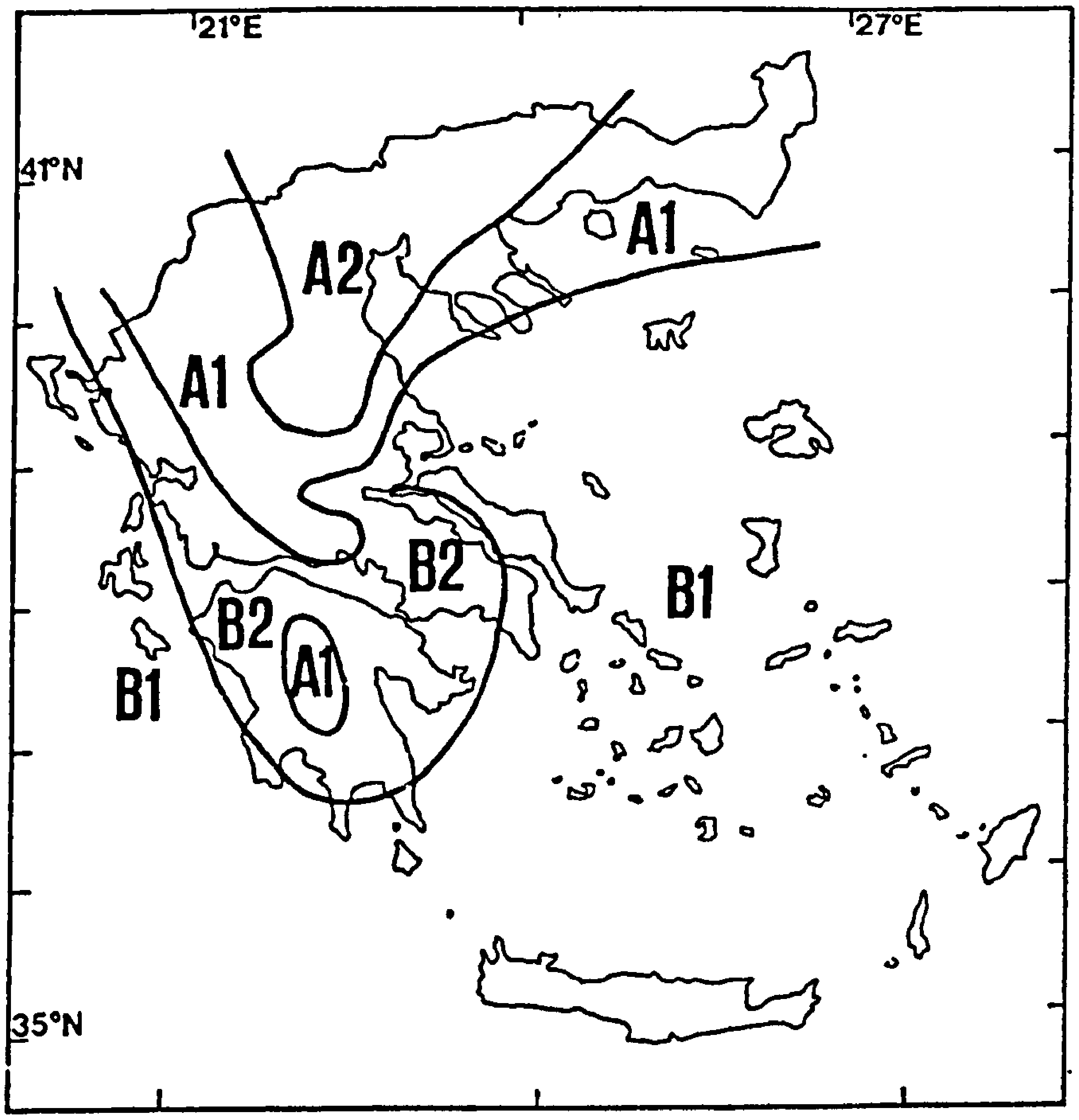


Figure 3. 11: Building Climatic Regions of Greece

This division of Greece into climatic regions is based on the thermal building characteristics predicted to produce the most effective passive control of indoor climate. The mean daily maximum and minimum temperature and relative humidity data of 39 Greek meteorological stations have been plotted on the BBC for twelve months in each case (from the 86 meteorological stations operating in Greece, 39 give full data which have been recorded over more than 10 years, the minimum period considered sufficient for a climatic analysis).

By examining the "day" and "night" conditions of each month as well as the duration of cooling and heating periods, the locations have been divided into four groups. The locations of each group have been placed on the map of Greece and it was found that they define four climatic regions (namely A1, A2, B1 and B2). Furthermore the wind, precipitation and sky conditions have been examined to define their ranges within each climatic region. The characteristics of the climatic regions are summarized in Table 3.2.

Table 3. 2: Characteristics of Climatic Regions of Greece

Climatic Region	**A1**	**A2**	**B1**	**B2**
Artificial Heating required (months)	7-8	6	3-4	4
Passive Heating possible (months)	2-3	2	3-4	3-4
Passive cooling possible (months)	2-3	4	4-5	4-5
Wind Speed in August (m/s)	1.5-5.5	1.5-3.5	3.5-8.5	1.5-5.5
Sunshine hours in January	80-100	80-100	105-160	105-160
Annual rainfall (mm)	>750	>500 but <850	>750, <500 central Aegean Sea	>750 west, <500 east

For the current study, the division of Greece in climatic zones will be examined according to the latter method for two main reasons:

1. It is a more recent study (1989) and the Greek Building Regulations have not been revised since 1979
2. More climatic variables are taken into considerations for the division of the different climatic zones.

3.3.2.4 The Greek Climate and the Application of the Thermal Comfort Zone

As it was discussed before, the impact of climate and prevailing weather conditions affect the heat balance between the human body and the environment and are the source of possible discomfort conditions. The Greek climate is classified in the temperate type, which includes cold and hot seasons. Therefore, it spreads above and below the thermal comfort zone. Some heating or cooling is required to increase or reduce the temperature, in order to be inside the thermal comfort zone. In addition, special care must be taken so that the RH levels will fall inside the limits of the thermal comfort zone.

The aim of a climate sensitive design is to ensure comfortable conditions using the minimum artificial heating or cooling. Especially during summer period, unpleasant climatic conditions have a direct impact on energy consumption of buildings for air-conditioning purposes.

3.3.3 Climatic Data for Ioannina

3.3.3.1 General Climatic Features

Ioannina is the city where the case study is located, situated in Zone A2. It has a population of approximately 100,000 is the capital of the region of Epirus situated in the North West of Greece and spreads around the shores of lake Pamvotis. Climatic data for Ioannina is summarised in Table 3.3 and in Figure 3.12.

Table 3. 3: Summary of climatic data for Ioannina, GR

IOANNINA, GR	*altitude 483m, latitude 39.42'N, longitude 20.48'E*				
	JAN	**APR**	**JUL**	**OCT**	**YEAR**
Mean Temperature (C)	5	13	26	15	15
Maximum Temperature (C)	9	18	31	21	20
Minimum Temperature (C)	1	7	16	9	8
Relative Humidity (%)	77	67	51	71	67
Cloudiness (octal)	5	5	2	4	4
Sunshine (hours)	96	180	316	179	2250
Rainfall (mm)	163	85	32	129	1300
Rainfall (days)	14	13	5	11	130
Snowfall (days)	2	0	0	0	7
Frost (days)	12	1	0	1	40
Thunderstorm (days)	2	2	5	3	40
Fog (days)	4	1	0	5	30
Prevailing Wind	SE	SE	NW	SE	

(Average values for a period of at least 50 years)

Cold winters and mild summers characterize its climate. January, February, March, November and December are substantially under heated. January and February are the coldest months were the temperature could be as low as –11^{0}C. While the sun can supply some of the daytime heating requirements of, thermal radiation, either from systems heated up during the day or independently has to be supplied for comfort.

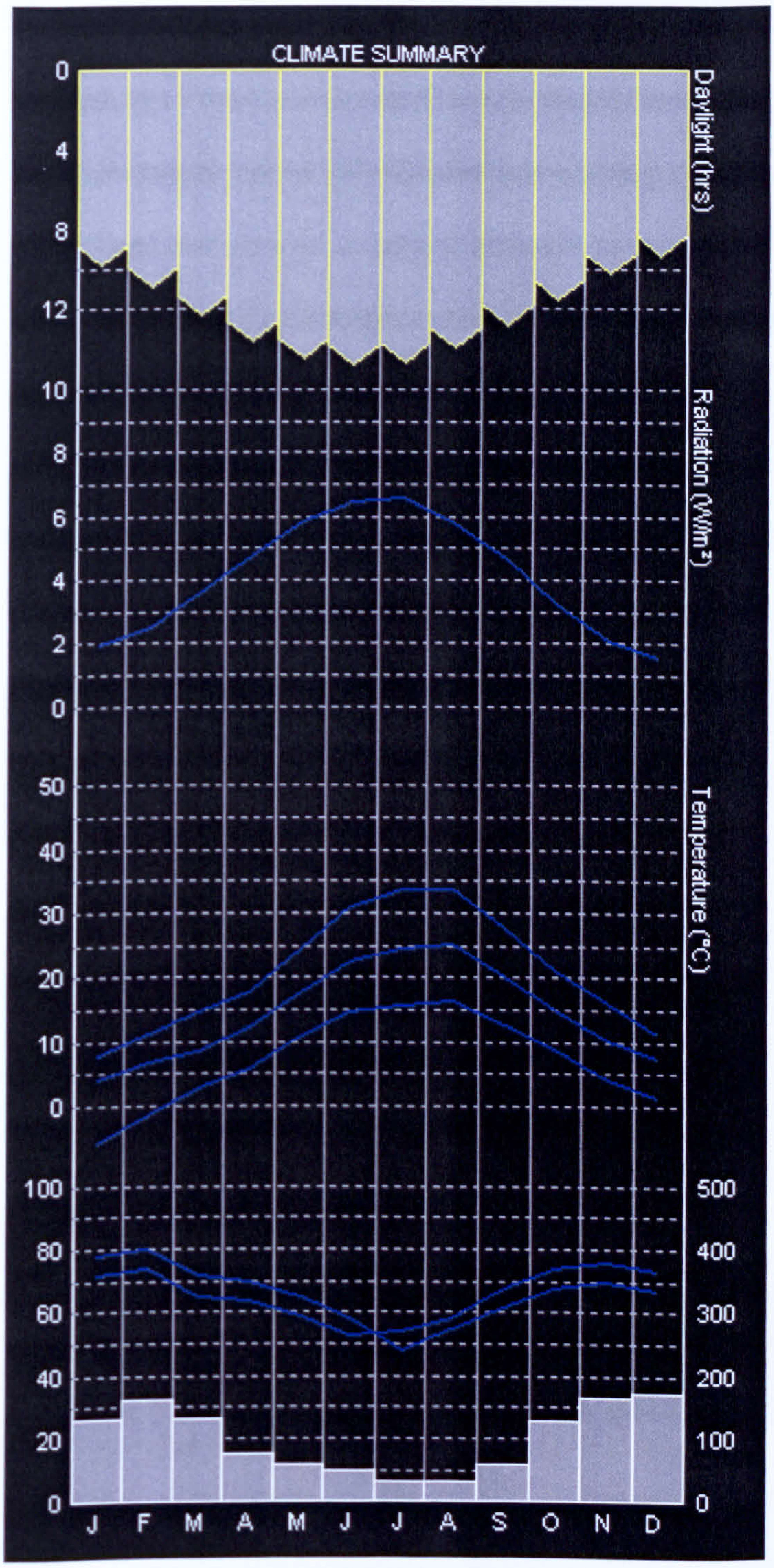
Humidity can reach high levels due to the presence of the lake. During January, February, November and December the relative humidity is higher. Overall, the second half of the year humidity is lower during the day than during the night.

The months of April and May are transitional from winter to summer. March and April will have cooler nights. During the month of May there will be warm to moderately hot days with comfortable nights and 60% relative humidity.

July and August are the hottest months where the temperature would hit over 35^{0}C. Relative humidity is around 50% so during these months most of the nights will be more comfortable than the days.

September is the transitional month from summer to winter, with comfortable conditions whereas October is colder and more humid.

Conventional constructions can provide thermal comfort in summer and pitched roofs are required because of the high precipitation levels. The wind speed in summer makes it easy to use natural ventilation for cooling during the night.



Daylight (hours)

Daily Solar Radiation (W/m^2)

Maximum Temperature (^{0}C)

Average Temperature (^{0}C)

Minimum Temperature (^{0}C)

Relative Humidity 9:00a.m. (%)

Relative Humidity 3:00p.m. (%)

Rainfall (mm)

Figure 3. 12: Graphic representation of climatic variables for Ioannina, Greece

(Chart produced from ECOTECT Weather Tool)

Figure 3.13 shows the Heating and Cooling Degree days for the same region[4]. According to the new Greek Thermal regulations, the heating requirement temperature for Ioannina is below 19 ^{0}C and the cooling requirement temperature is 26 ^{0}C. The graph was considered a critical addition to the climate analysis, since the information provided from it is directly related to the energy requirements of a building set in the specific climatic context. As it can be seen form the graph, the heating requirements (2027 hours) over rank the cooling requirements (231 hours). The value of this observation should be reflected on design decisions: an atrium building can be overheated during summer and require careful cooling design strategies, but in a climate like this, equal consideration is required for heating during winter months.

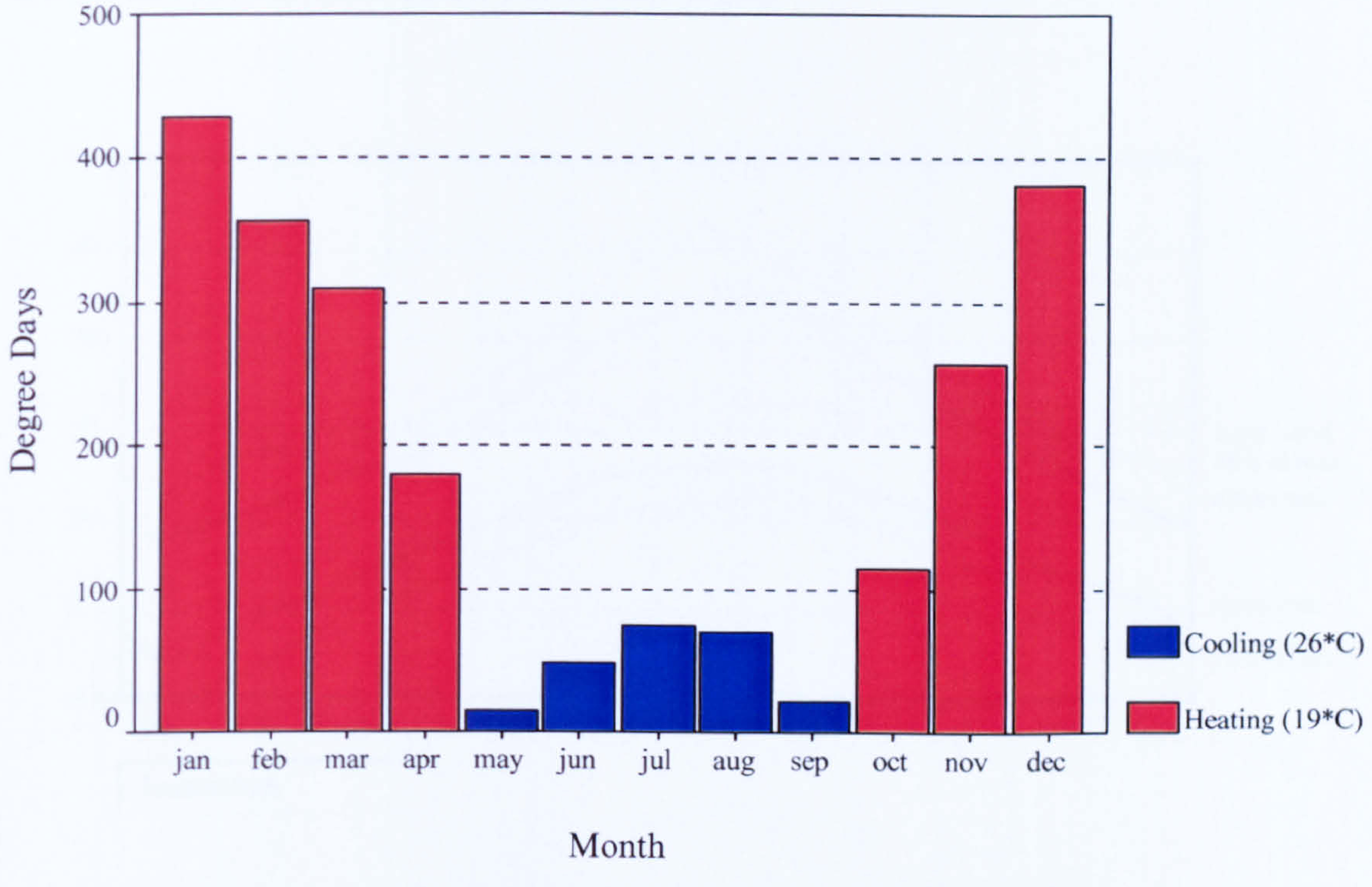


Figure 3. 13: Heating and Cooling Degree Days for the Ioannina (Greek Thermal Regulations)

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[4] Heating degree days are indicators of household energy consumption for space heating. It was found that for an average outdoor temperature of 18^0 C , most buildings require heat to maintain a 21^0 C temperature inside. Similarly, for an average outdoor temperature of 18^0 C or more, most buildings require air-conditioning to maintain a 21^0 C temperature inside. In the current research the heating requirement temperature is below 19^0 C and the cooling requirement temperature is above 26^0 C. Source: http://www.wunderground.com/about/faq/degreedays.asp

In the next paragraphs, the bioclimatic charts for Ioannina are analysed and the potential for passive design strategies are explored in order to achieve thermal comfort.

In order to shape the bioclimatic charts for Ioannina, data for the local climate were collected and calculated. In Figure 3.14 the climate lines for each month is plotted as the 14th and 86th percentile values (green lines) of daily minimum and maximum temperatures (blue lines). It also indicates that for 72% of the time the temperatures are likely to be between the two green lines. The diagram gives a visual indication of the nature of the climatic problem. For the same period and climate, the red zone indicates the comfort zone. It also shows that for the period May to October the ambient climate is within the comfort zone. From November to April the ambient temperatures drop quite below the comfort zone.

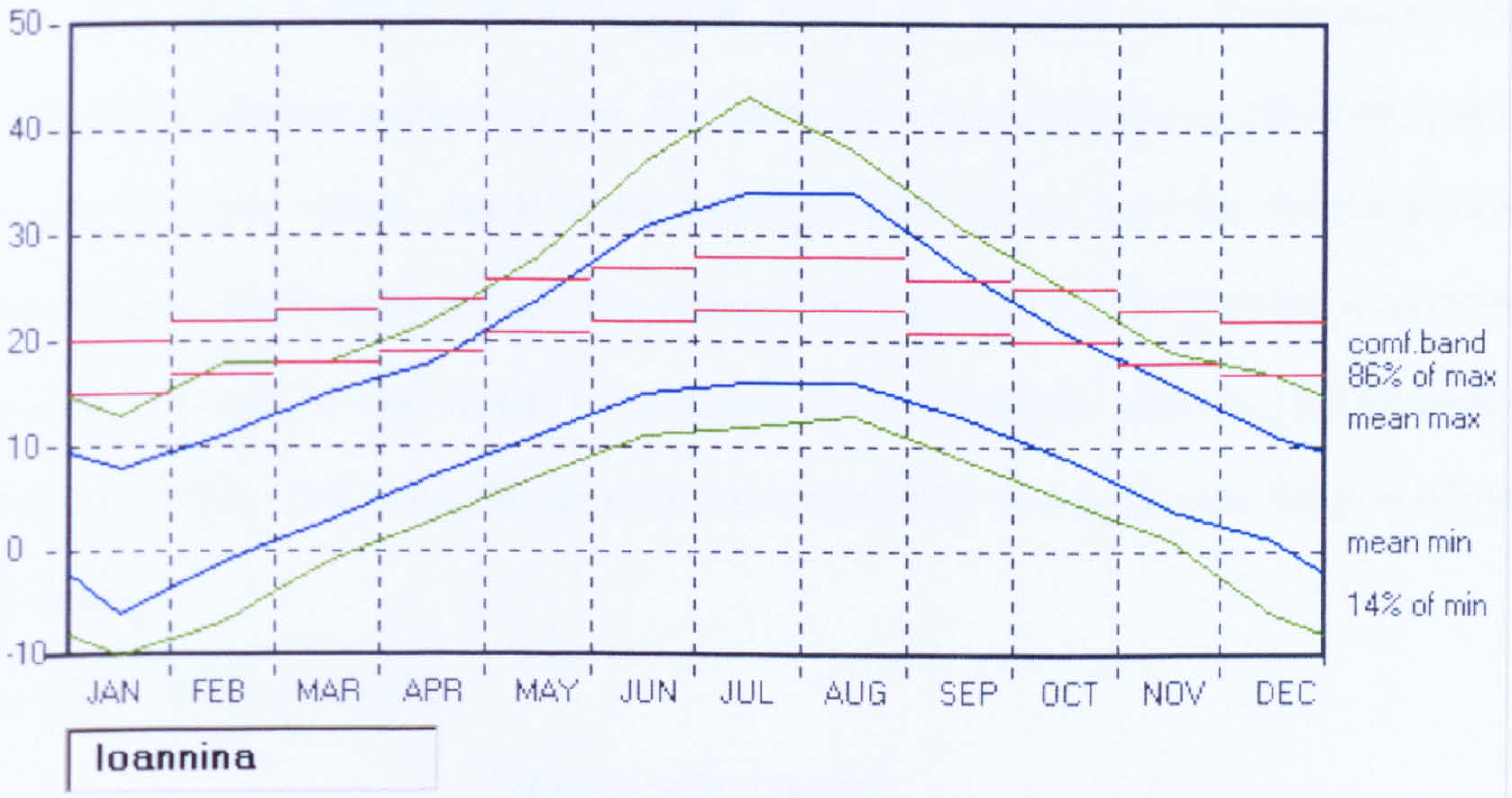

Figure 3. 14: Plot of the climate of Ioannina for a 12-month period (ARCHIPAK)

Climate analysis and thermal comfort zones for Ioannina, was plotted on the psychrometric chart (Figure 3.15). It illustrates the position of summer and winter comfort zones compared with the climate plot for Ioannina. The 12 lines, (one for every month), plotted on the psychrometric chart represents the climate. The comfort zone is calculated (separately for January with the blue line and July with the red line), indicating the range of acceptable indoor conditions. The upper summer limit is extended with the red dotted line. By plotting the monthly temperature values on the psychrometric chart, it becomes much easier to visualize the climatic conditions for each month. Even by visual inspection alone, some key facts about the climate can be determined.

As it can be seen, the climate of Ioannina includes distinct cold and hot seasons, i.e. above and below the thermal comfort zone. It is also clear that the two comfort zones do not intersect and have very distinguished boundaries. The 12 lines representing the climate plotted on the chart indicate that there are wide variations between winter and summer i.e. cold in winter and quite hot during summer months while the long lines indicate large diurnal variations.

The ideal solution for a designer would be to achieve comfortable indoor conditions by passive controls alone. But even if no such solution is obtained, passive controls, in most cases, could work together with active controls (heating/cooling systems) and significantly reduce the energy requirement. In ARCHIPAK, a system of analysis is described that assist in selecting the appropriate passive control strategy (Szokolay 1995). The possible passive thermal control strategies can be summarized as follows:

For underheated conditions:

Passive solar heating

Mass effect: thermal storage

For overheated conditions:

Mass effect: thermal storage (also with night ventilation)

Air movement effect

Evaporative cooling

The task of the following charts is to define the zone of outdoor temperatures and humidities within which the particular control strategy has the potential of creating acceptable indoor conditions, referred to as the control potential zone, or CPZ (Szokolay 1986). How this potential can be realized, how this strategy can be translated into an actual design will be examined in the following chapter through the simulation and the parametric study.

3.3.3.2 Bioclimatic Chart Analysis

3.3.3.2.1 Passive Solar Heating

Passive solar heating refers to the use of direct solar radiation to heat a space in winter. This can be achieved using a direct-gain system, such as the atrium space, in which sunlight passes through the transparent aperture directly into the habitable space, or indirectly where a separate solar collector is used; then the heat is transferred to the space via a medium (i.e. water). There are a number of building parameters that control the effect of this kind of system like the glazing ratio, the insulation of the building envelope and the system efficiency.

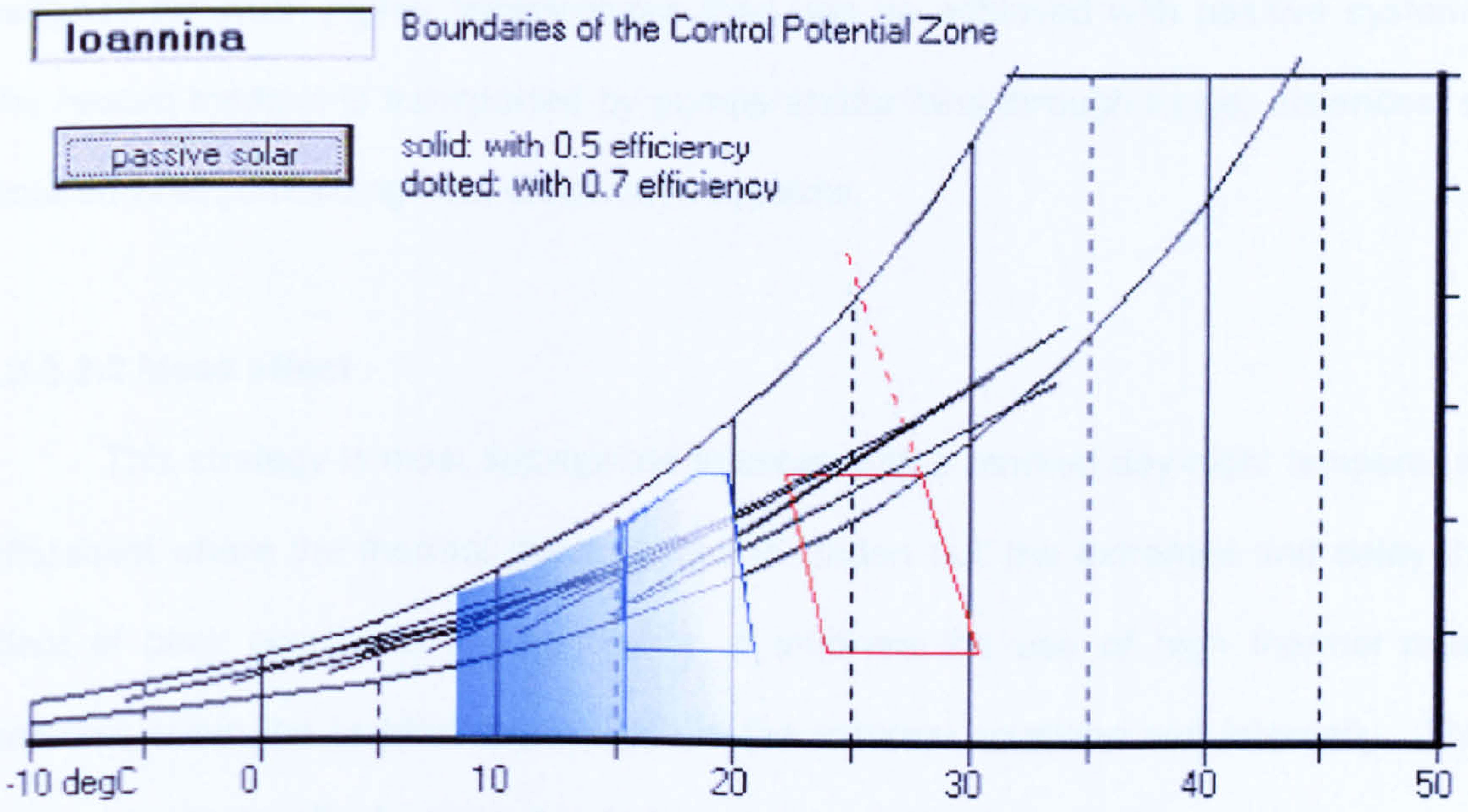

Figure 3. 15: The psychrometric chart indicating the comfort zones with passive solar heating

The outer limits of the 'passive solar' zone on the psychrometric chart are defined by winter outside air temperature and by the amount of available daily radiation, given by the latitude and local sky clearness conditions as a function of altitude, local climate, or pollution. Also, the ratio between glass and floor area would be important. Assuming clear sky conditions, the total daily insulation on each square foot for south-facing glass is about 1500 Btu[5] at 40°N. If this is captured by a building with 1/5 m^2 of its total floor area of south-facing glass with 33% efficiency for collection, comfortable indoor conditions can theoretically be maintained for one day without supplemental heat; that is even if the most severe average daily temperatures range is more than 8°C. Figure 3.15 shows the extended comfort zones for Ioannina with the application of passive solar heating and with system efficiency $\eta=0.5$ and $\eta=0.7$.

When passive means fail to provide thermal comfort conditions during low temperatures, the other strategy that can be applied is using either 'active' solar system or/and conventional heating by gas or electricity. In an active solar heating system, the collection and storage components are separate from the interior volume and are designed for much higher temperatures than can be achieved with passive systems. The heated medium is transported by pumps and/or fans through longer distances, as required in large-building heat distribution systems.

3.3.3.2.2 Mass effect

This strategy is most appropriate in areas with a marked day-night temperature differential where the thermal mass serves to 'flatten out' the extremes and delay the effect of peak conditions to the interior. It involves the use of high thermal mass materials within the building fabric, both in the external envelope and internally. This has a capacitate effect, which tends to even out both diurnal and seasonal internal

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[5] BTU OR BRITISH THERMAL UNIT – A unit for measuring energy, equal to the amount of energy needed to increase the temperature of 1 pound of water by 1 degree Fahrenheit. *Source:* http://hearth.com/what/glossary.html

temperature fluctuations. Even when the daily temperature variation is as high as 18°C, a 30cm brick wall should result in an indoor temperature variation of about 9.4°C, with a time lag of about 12 hours. It means that the coolest part of the night is felt indoors at mid-afternoon. This process of sensible cooling leaves the moisture content of the air unaffected.

Figure 3.16 shows the comfort zone for Ioannina with the use of mass effect. The change in the comfort zone on the psychrometric chart is distinguished by horizontal extension to the left for the winter and to the right for the summer, along the lines of constant moisture. There is no change in absolute humidity, i.e., the number of water vapour molecules remains the same. Below the lower boundary of this zone, it is too dry for comfort, and high-mass construction will have no effect on this problem. Above the higher boundary of the zone, it becomes too humid for comfort. And if the temperature falls below the dew point, since there is no change in the moisture content except by precipitation, the problem becomes one of the structure heating or cooling respectively too slowly; that of high humidity and temperature.

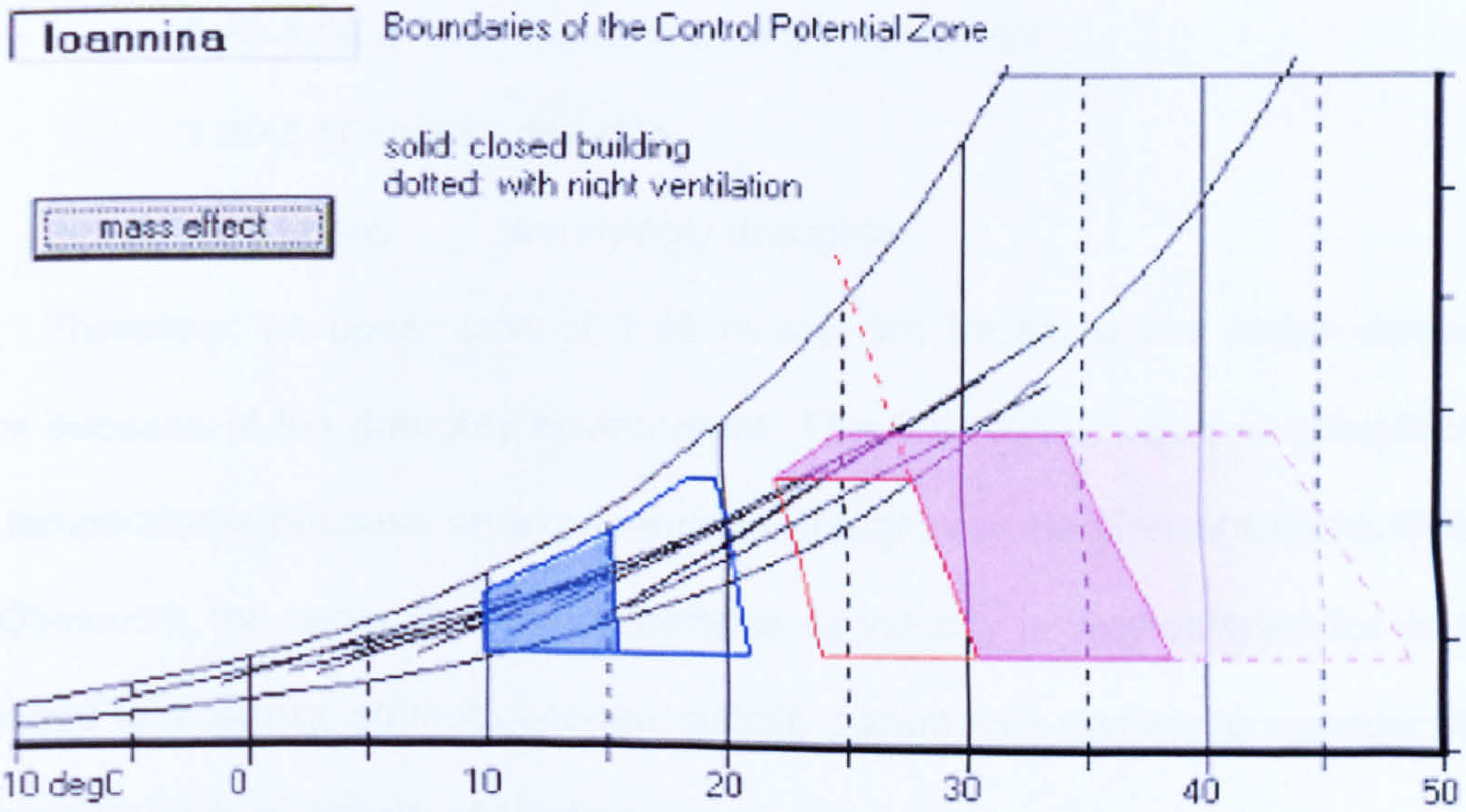

Figure 3. 16: The psychrometric chart indicating the comfort zones with mass effect

During winter, for a high mass building, the comfort stretches down to 10 ^{0}C of ambient temperature, whereas for summer the comfort limit is around 39 ^{0}C of ambient temperature. With the application of overnight ventilation the building fabric would cool down, even if the upper limit of outdoor temperature reached as high as 48 ^{0}C.

3.3.3.2.3 Air movement effect

When the daily temperature range is not high enough to make thermal mass effective, it is possible to maintain comfortable indoor conditions simply by designing the building to be exposed to prevailing breezes and to utilize resulting positive and negative air pressures to maintain airflow through the interior. It is known that as air velocity rises, the air temperature in which one feels comfortable rises as well. However, there is an upper limit to air velocity above which air movement itself causes annoyance. According to Olgyay (Olgyay 1992) and Szokolay (Szokolay 1980), the effect of air movement alone for temperatures around comfort is as follows:

Up to 0.25 m/sec : unnoticed
0.25-0.50 m/sec: pleasant
0.50-1.00 m/sec: awareness of air movement
1.00-1.50 m/sec: draughty
above 1.50 m/sec : annoyingly draughty

Therefore, an upper limit of 1.50 m/sec can be set above which discomfort begins because of the draughty environment. The 1.50 m/sec value is acceptable for high temperatures because an experience of draught can be pleasant if one feels too hot. Obviously, the upper limit of comfortable air velocity is very different for an office compared to a factory, so that occupant activity parameters come into consideration in establishing limits of natural ventilation.

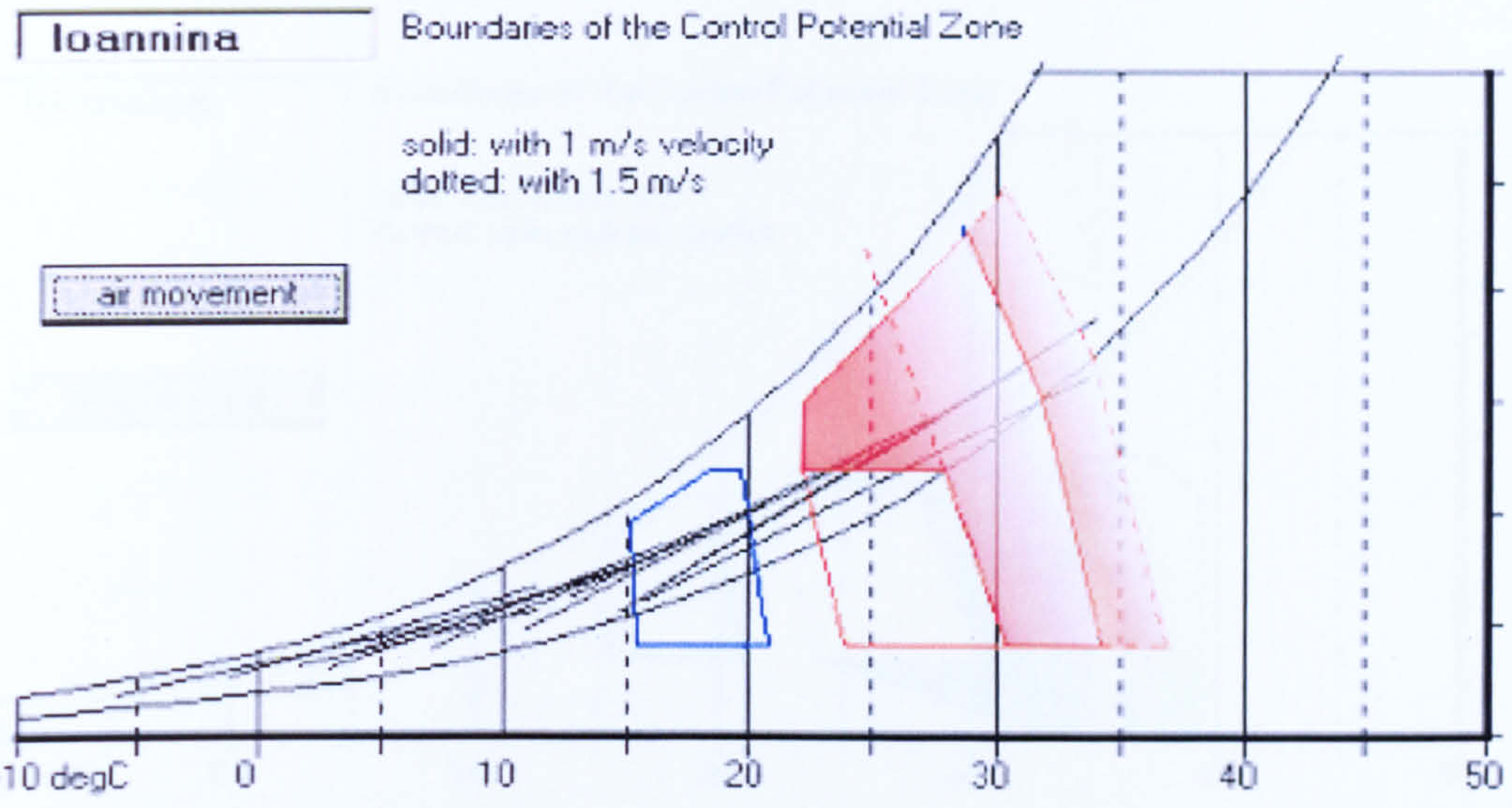

Figure 3. 17: The psychrometric chart indicating the comfort zones with air movement

On the psychrometric chart (Figure 3.17), the comfort zone is extended by this strategy to between 20%-90% relative humidity. By opening up the building whenever overheating occurs to take advantage of cooling breezes, even if the air is warmer than the skin (up to 38 ^{0}C) (Docherty 1999) the comfort zone stretches to 34 ^{0}C with 1m/sec air velocity and to 37 ^{0}C for 1.5m/sec of air velocity. This phenomenon utilizes the evaporation of sweat to provide localized body cooling.

3.3.3.2.4 Effect of Evaporative Cooling

This strategy is effective in periods with high temperatures and low humidity (summer in Ioannina). Thermal comfort is achieved by cooling the ambient air by spraying or dripping water through a specially designed intake chamber or by blowing the dry air through a wet cloth or porous fibre mat. When water is evaporated, cooling takes place because the energy needed to change water from the liquid state to gas comes from the reduction in temperature of the surrounding air. The cooled air is generally close to 100% saturation; it cannot be recycled, and must be continuously thrown away and replaced with freshly moistened air.

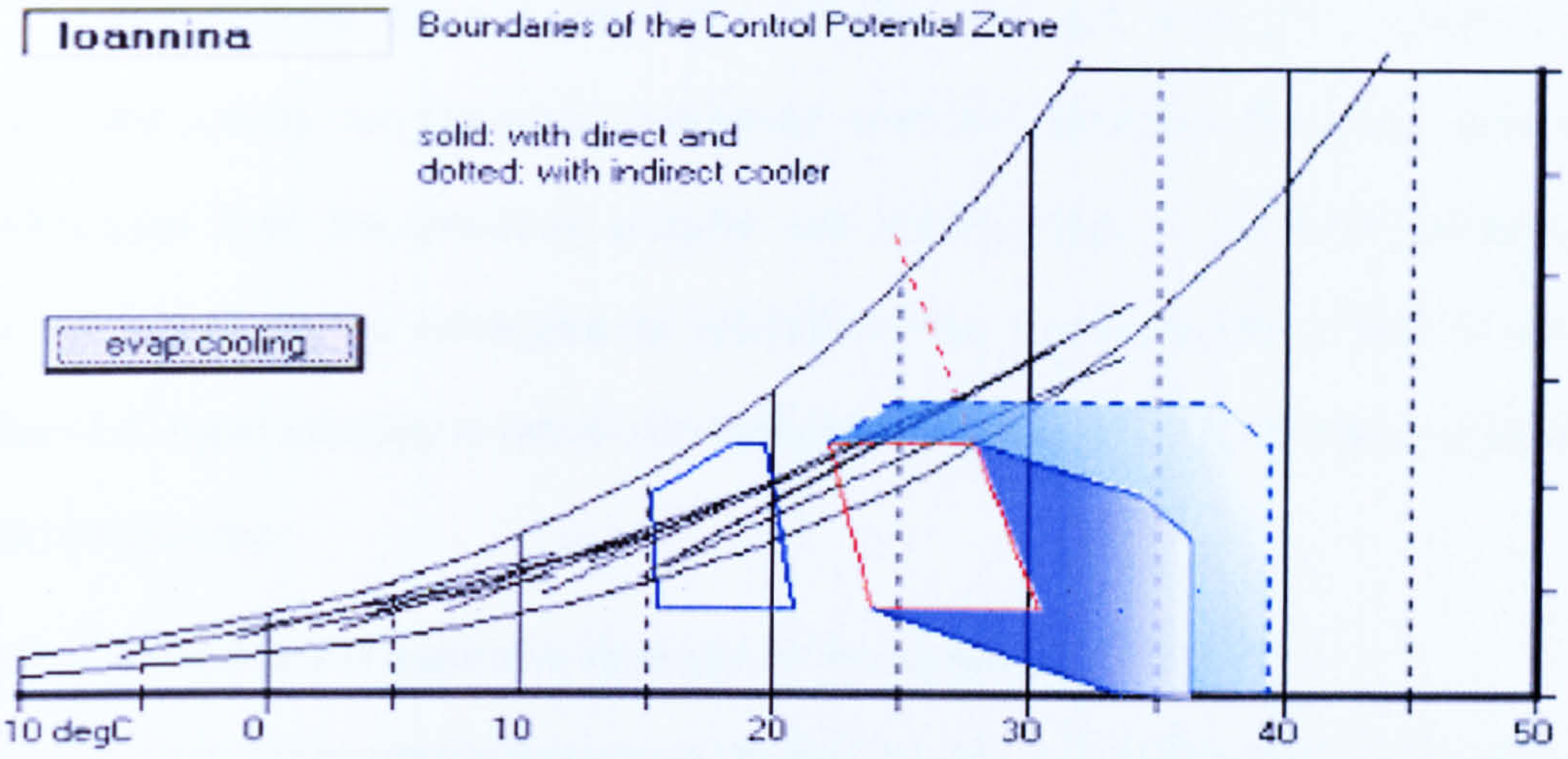

Figure 3. 18: The psychrometric chart indicating the comfort zones with evaporative cooling

The effect of evaporative cooling to the comfort zone of Ioannina is shown in Figure 3.18. By definition, no energy is lost or gained in the process, which means that it must follow one of the lines of constant energy (enthalpy), which run diagonally down to the right. This explains why the evaporative cooling zone extends downward at an angle. Its outer boundary is defined only by the cooling capacity of the volume of air that can be comfortably moved through the interior of the building.

The solid blue line represents the comfort limit with the use of direct evaporative cooling, which can be very effective in a dry summer atmosphere. The blue dotted line represents the comfort limits for Ioannina with the use of indirect evaporative cooling: in this system evaporative cooling occurs external to the space. The cooled air then interacts with the supply air via a heat exchanger. This way there is no addition of moisture to the air entering the space even if the cooled air approaches saturation. This means increased effectiveness even if there are losses in the heat exchange as more vaporization can be allowed.

3.3.3.2.5 Applicable Strategies for Ioannina

The various thermal comfort strategies derived from the analysis of the bioclimatic charts for Ioannina, combined with the analysis of atrium and energy contribution from the previous chapter are summarised in this final paragraph. A comparison of all the strategies as plotted on the psychrometric charts is shown in Table 3.4. Each strategy is rated with respect to which months they have an effect and how extensively.

Table 3. 4: Summary of applicable strategies for the climate of Ioannina[6]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Passive heating of high-mass structures	√√	√√	√√√	√√√	√√				√√	√√√	√√	√√
Active solar systems or conventional heating methods	√	√									√	√
Passive cooling of high-mass structures					√	√√	√√	√√	√			
Natural ventilation for cooling						√√	√√	√√				
High-mass structure and night-time ventilation for cooling					√	√√√	√√√	√√√	√			
Evaporative cooling					√	√√	√√	√√				

An atrium space, with a large south-facing glazing area, can be endowed with large solar gains, used for the heating of the adjacent building in order to maintain comfort levels without any additional mechanical heating. The heat gains depend, amongst others, on the amount of atrium glazing and its orientation, therefore attention should be paid to the latter and the size as well as the properties of the atrium glazing. Heat can be stored in the atrium and adjacent building's walls and floors. The amount of heat stored depends on these elements' thermal mass. The latter (e.g. ratio of glazing facing the atrium) will also affect the amount of heat transferred between the atrium space and the adjacent building. In the parametric analysis, variations of the adjacent building's glazing ratio facing the atrium will be explored.

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[6] √ = little effect, √√ = medium effect, √√√ = large effect

The atrium solar gains have a substantial potential for contribution in heating requirements for the months of March, April, the second half of September, October and the first half of November.

December, January and February are the coldest months of the year. Also, during the months of November, December and January, the mean daily global radiation on south-facing surfaces reaches its lowest value. Subsequently, passive solar devices will not provide comfort throughout and the atrium will act mainly as a buffer space. During these colder months, comfort will be dependant mostly on conventional heating methods for the adjacent buildings. Whether comfort levels can be maintained inside the atrium space without the aid of artificial heating will be explored later in the parametric analysis and will depend on the results from the thermal comfort survey, analysed in chapter 5.

May and September are transitional months when it is cool during nights and comfortable during the days. Solar passive systems can really be efficient by keeping cooler ambient temperatures within comfort.

During June the nights are comfortable while the days are generally warmer than comfort. In this case, thermal mass cooling can be effective during the day but not during peak hours. Night time ventilation of the thermal mass can be also useful through the atrium space.

The hottest months are July and August with the lowest levels of RH. During these 2 months, June, and the first part of September, the atrium will have excess solar gain and potentially create highly uncomfortable conditions especially during late afternoon hours. Here, natural ventilation will work well with relatively high wind velocity or air movement. This way, all but the peak hours can be within comfort.

Summarising the above thermal comfort strategies that will work for the whole year and would be applicable in the case of the atrium building: the use of thermal mass for heating and cooling (mainly the walls and surfaces of the adjacent to the atrium building), evaporative cooling for the hottest months, natural ventilation for hot months if possible and conventional heating for the adjacent building for two or three months. The need for a combined use of passive design methods is unavoidable; the climate of Ioannina, as presented in Table 3.4 and the monthly plots in the psychrometric charts, has wide diurnal variations. Therefore, a technique to exhaust excessive heat during day could have a negative effect during night. Thus it is understandable how this kind of analysis makes the climate for a site more explicit and assists in defining the most efficient design elements from the very first steps of design.

3.4 Conclusion

In this chapter, it was established that a building might be considered as a '*climate modifier*', which shields the indoor environment from the external climate.

Before embarking on the design a building in a certain location, the changes of weather from season to season (i.e. the climate) must be well understood so that the building can be built to shelter people all the year round. In order to assess the climate in a certain location, the climatic data has to be studied and, for the benefit of energy efficiency as well as comfort, to apply this knowledge for evaluating and determining design options and strategies. This can be done with the use of the bioclimatic charts that offer options of building design guidelines can be explored in order to maximize indoor comfort conditions when the building's interior is not mechanically conditioned.

For the current study, the focus was on the Mediterranean climate and in more specific, the climate of Ioannina in Greece. A detailed analysis of the case study climate was carried and with the use of bioclimatic charts design options for passive solar techniques were proposed. This information will be used as an input in the thermal simulation programme and the forthcoming parametric analysis.

The following chapter focuses on the environmental performance of the glazed courtyard through an analysis of the physical measurements and the comparison of the results with those predicted from a dynamic thermal simulation programme.

CHAPTER 4

Thermal Performance of an Atrium Building in a Mediterranean Climate

4.1 Introduction

As stated before, this research combines the study of thermal comfort and thermal performance, as it is the aim to optimise, through design, buildings' performance. The two topics are usually treated separately and in the current study there is an attempt to study both in order to explain the thermal performance of atrium buildings set in a specific climatic context. To this end, this chapter attempts to evaluate the thermal conditions that occur in an atrium building set in a Mediterranean climate.

The chapter consists of two main parts: the first part looks into the thermal performance of an atrium building in the climatic context of Greece. The method used to assess the thermal performance involved taking physical measurements of the internal environment over a three-month period for each main season i.e. the cool season (December/January/February) and the warm season (June/ July/ August). The atrium space is measured providing data sets of air temperature, relative humidity and light intensity in conjunction with external weather measurements over the above periods. The ambient climatic data were provided from the Laboratory of Meteorology, Department of Physics from the University of Ioannina. The focus is mainly on the climatic performance of the building and the assessment of thermal performance a one-week period was selected for each season in order to investigate climatic fluctuations inside the atrium space.

The second part focuses on the use of a thermal simulation programme in order to model the building and to allow the comparison of measured and predicted data, which in this study was seen as the most suitable approach to validation of the programme for use in parametric studies.

4.2 The Case Study

4.2.1 Site and Building Description

Different types of atria were analysed in chapter 2. The selection of this building was based on choosing the most representative and simple type of atrium; a fully enclosed, rectangular-shaped glazed courtyard. The case studied is a University building in the city of Ioannina. Ioannina is a city in the North-West of Greece (Figure 4.1) and its climate was discussed in detail in Chapter 3.

The new School of Philosophy building is located at the University campus, approximately 10 Km S.W. of the city of Ioannina and about 2 Km off the main highway joining Ioannina to Athens. The building was constructed in the 1970's and is composed mostly of two joined quadrangles built around two courtyards of 600m^2 and 700m^2 respectively. The latter is glazed and its basic dimensions are 19.60 x 36.00 m approximately. The surrounding building is composed of two-storey and three-storey sections and its southern part is founded one level lower than the northern part (a height difference of 3.80m), roughly following the contour lines of the natural ground. The building is designed to shelter all School of Philosophy activities, mainly classrooms and meeting rooms, personnel offices, secretariat, library, research quarters, conference rooms and a coffee place. Within a European project looking into the applicability of retrofit applications of passive solar systems in buildings in Mediterranean, a proposal was designed and constructed in 1987 for the glazed covering of the one of the two courtyards. Two sides of the ground level in the Southern part of the building are on pilotis[1], which is the main reason for not applying the project to both courtyards.

The building was designed before the 1973 energy crisis, and no provisions had been made for energy conservation measures i.e. double-glazing, insulation of wall and floor surfaces.

Prior to the construction of the roof there was extensive simulation of the building by the design team, indicating important energy savings for heating and cooling. The scope of the designers was also to improve the livability of the atrium and the surrounding spaces, to increase thermal comfort and day lighting levels as well as to create a transitional space sheltered from noise and external climatic conditions.

Figure 4. 1: The map of Greece showing the location of Ioannina and a view of the city

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[1] A series of columns or piles esp. used to raise the base of a building above ground level. *Oxford English Dictionary, 2nd Ed.*

The section of the building affected by this project has a total covered surface of $400m^2$ surrounding a courtyard of approximate $700m^2$. It's a pilot study of passive solar retrofitting (Figure 4.2).

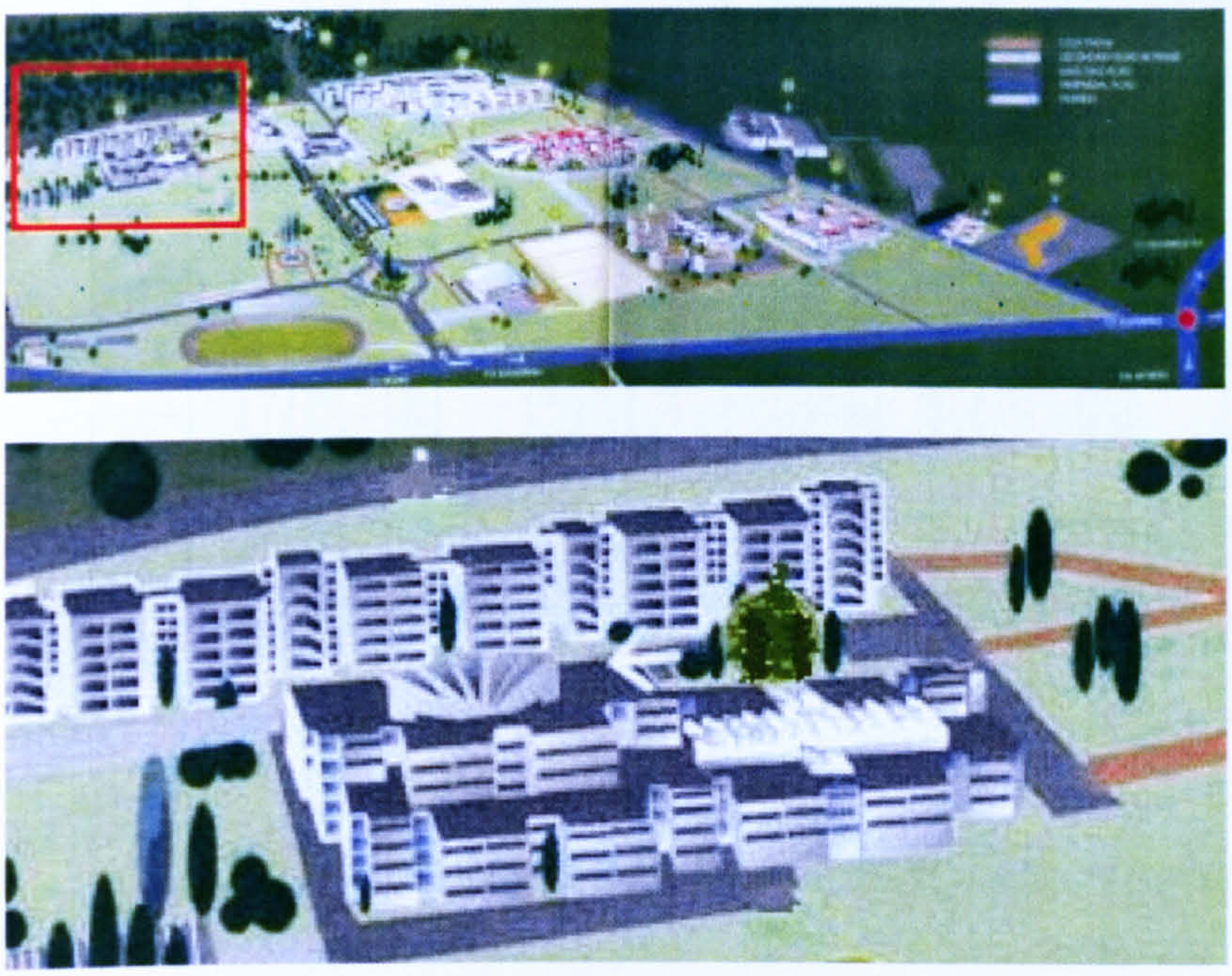

Figure 4. 2: Map of the University Campus of the University of Ioannina indicating the location of the atrium building in the campus.

The operating principle for the project was based on the conversion of a central atrium space into a giant greenhouse by the means of a specially designed passive solar roof, which would help to passively collect solar energy in the atrium space (Figure 4.3).

Although the design team, in the case of the school of Philosophy building, did not consider architectural style considerations as the primary consideration, it was strongly felt by most participants and future users that this design should add some visual excitement to this otherwise rather colourless modern University building. It was also hoped that besides its energy contribution the covered atrium space would also enhance the building's liveability by creating a sheltered transition space quite useful in Ioannina, where rainfall levels are some of the highest in Greece (Stourna-Trianti and Santamouris 1984).

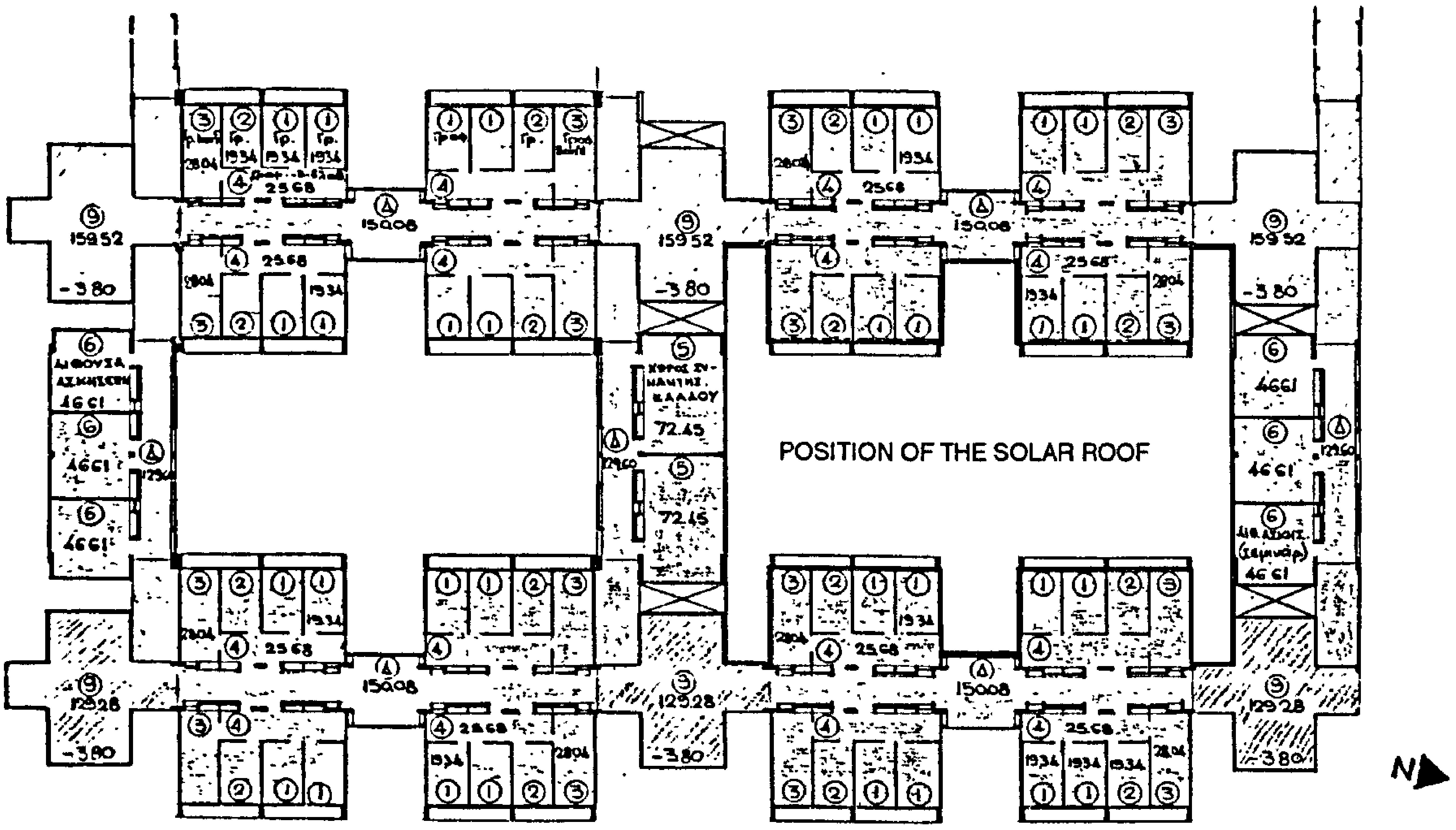

Figure 4. 3: The site-plan of the building of the Philosophic School of Ioannina

4.2.1.1 Description of the solar roof and building materials

The architectural design solution chosen for the solar roof over the School of Philosophy building atrium was a shed-type roof; successive pyramidal shed-units are formed, offering triangular South or South-West and South-East while oriented collections surfaces are disposed in such a way that no shading can occur between one shed-unit and its immediate neighbours (Figures 4.4, 4.5, 4.6 and 4.7). The design team was involved in previous studies (Santamouris M. 1983), (Stourna-Trianti and Santamouris 1984) where the shed-type roof indicated to offer the best thermal performance in Greek climatic conditions, combining as it does good winter coverage with excellent summer shading and ventilation possibilities. The roof is supported by a light, three-dimensional steel structure. The shed covering material is a type of foam-insulation "sandwich" with finished inside and outside surfaces. This material covers all horizontal and north-facing surfaces of the shed-type roof, while double-glazing covers the vertical collection surfaces.

The transparent elements of the atrium walls above the 2nd floor are of tinted, glare-reducing glass. The final effect is one of a diamond-like roof configuration with a succession of high and low triangular collection surfaces, facing either South or Southwest and Southeast of the building in directions symmetrical to the building axis.

Figure 4. 4: The solar roof from the North

Figure 4. 5: The solar roof from the South

Figure 4. 6: The solar roof from the West

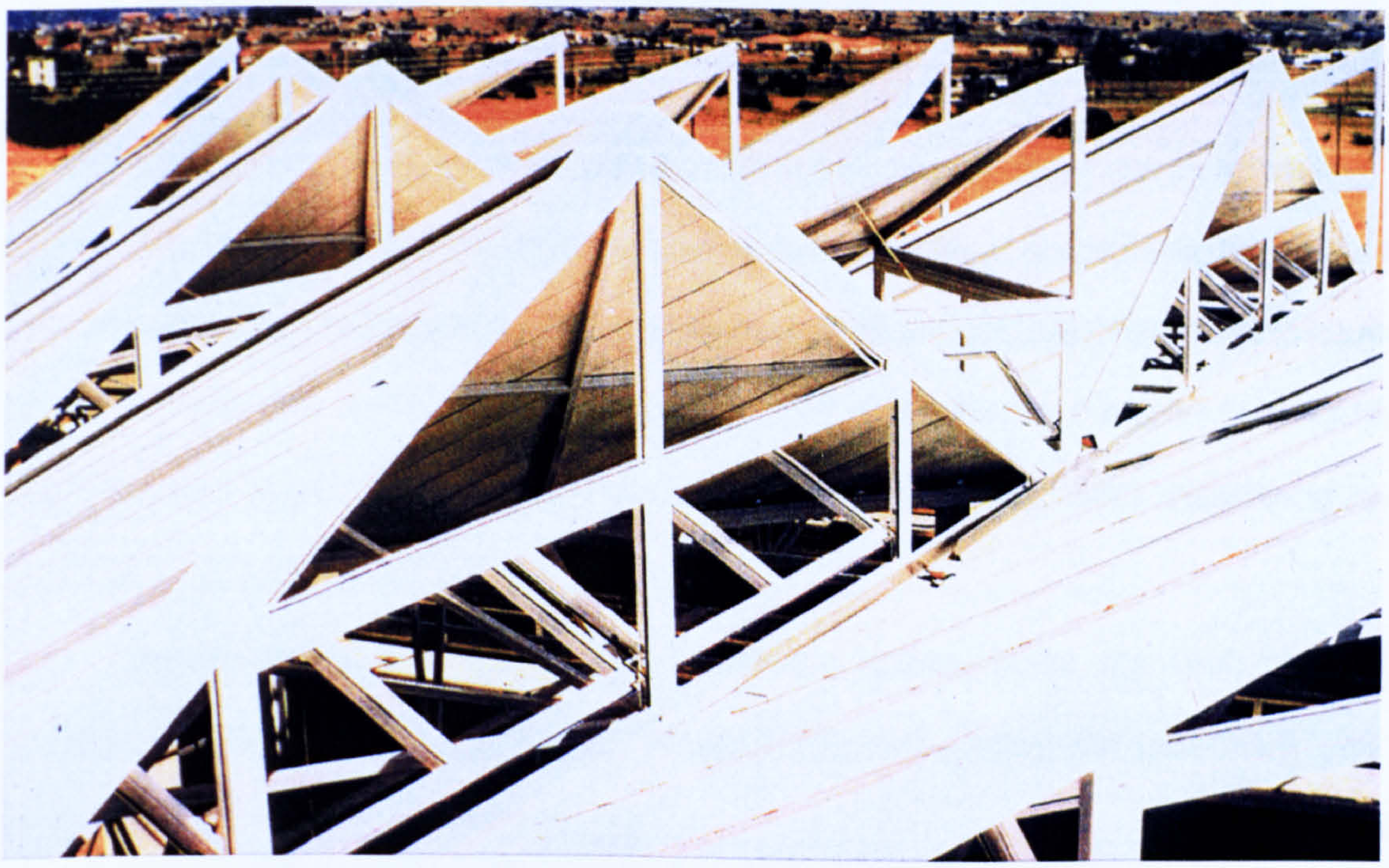

Figure 4. 7: Detail of the solar roof under construction

The building is aligned close to a North-South axis with a small inclination to the East. The shell of the building is made of reinforced concrete while the fillings of the walls is perforated brick. The thickness of the walls is 25cm. Floors are constructed with cinder blocks, shingle mosaic, shale, tiles, and marble and are 40cm thick. The net height of the building floor (floor to ceiling) is 3.70cm. The openings of the building are a series of 1.6mx1.00m double-glazing windows and of 0.5mx1.00m of scuttles.

4.2.2 Observations

Part of the research was the observation of the atrium space and of the users' every day activities for both seasons. This covered a period of two weeks in winter and three weeks during the summer. Such observation was considered essential in order for the researcher to become familiar with the space, to obtain a personal perspective of the thermal processes and the environmental changes inside the building as well as the way the occupants used the space.

All adjacent rooms of the building – occupied or not, were centrally heated, and during the winter months the heating was constant. Instant measurements taken by a thermometer inside the building during the cool season indicated that the temperatures inside the adjacent rooms were between 20^{0}C and 22^{0}C. During the summer months, air conditioning systems kept the temperature between 20^{0}C and 24^{0}C, depending on the ambient temperature.

There was a sense of humidity inside the atrium during the cool season and compared to the adjacent rooms, the climate inside was a lot milder (protected from rain and wind) than the ambient climate.

The atrium had no artificial lighting but only two small spotlights. The adjacent buildings did not light the atrium since the majority of the adjacent rooms were offices of the teaching staff and they are not used for long hours.

The atrium space was treated differently during the two seasons. During the cool season, it was a mainly a transitional space between the two buildings, the libraries and the classrooms. The absence of artificial lighting, especially after sunset, and the leaking of the roof were considered particularly uninviting for the users. However, there were still users, mainly students who would prefer to have a coffee break in the atrium space rather than in the cafeteria on the lower ground floor.

During the warm season the liveability of the space changes dramatically. Apart from a communication space it also takes the role of a meeting spot, a refreshment break, a gathering point. The prolonged sunshine hours enhance this until the late evening hours.

The smell of plants or the atmosphere in the atrium made the changes of the seasons real. The light and shadows inside the atrium also changed dramatically with the change of season; during winter the soft, low-angle sunlight cast the shadows of the metallic roof structure in the adjacent building's façade. During summer, diffused light was creating a pleasant indoor space.

It should be stated here that the majority of the occupant's interviewed found the atrium space an exhilarating space that they could use before and after the classes. According to those occupants that knew the building before the retrofitting and the covering of the courtyard, the project "added a valuable space" and some visual excitement. The "atrium" is now a feature for the school, as well as for the whole University.

Due to the arrangement of the school facilities around the courtyard, a large number of occupants have to use it as a transitional space between their working environments. In most cases, and especially for the winter season their clothing is not modified just because they have to "cross the atrium".

During the summer months the occupants found the atrium "a pleasant space" and were quite keen to spend their lunch or coffee break or meet for a casual talk with their colleagues. These findings were also reflected in the survey analysed in the previous chapter. Additional observations were made of direct radiation effects on occupant comfort and use of the space, effects of glare on vertical surfaces.

4.3 Building Performance Results

As stated before, the thermal performance of the building was assessed by air temperature and relative humidity measurements. The study was conducted for both seasons December 1999 /January /February 2000 and June / July / August 2000 representing the coolest and warmest periods respectively of the year.

The key point to be examined here was the extent to which acceptable indoor temperature ranges depend upon outdoor weather for both seasons and consequently for the whole year. Therefore ambient climatic data was required and the meteorological station of the School of Physics of the University of Ioannina, only within a distance of a few hundred meters from the atrium building, provided it.

4.3.1 Thermal Comfort Optimum Conditions and Acceptable Limits

Seasonal measurements were performed using the same type of instruments used in the measurement of climatic variables for the thermal comfort survey. The elements measured were average air temperature, relative humidity and light intensity.

In the current study it was decided to use the air temperature and relative humidity variables in order to determine the thermal comfort zone. The main reason was because the air temperature and relative humidity are the two climatic variables most easily understood by the occupants of an enclosed space and by designers less familiar with thermal comfort and building thermal indicators.

The measuring equipment (described in APPENDIX A) were positioned: one in the centre of the atrium at 1.00m height; and 2 were attached with adhesive tape to one of the metallic beams that support the solar roof at a height of 4,00m and at a distance no more than 1.00m from the atrium wall as shown in Figure 4.8 for both the monitoring periods. Due to equipment limitations, for the purpose of this study, the mean radiant temperature had to be considered equal to the air temperature measured by the data loggers. This is not an unreasonable assumption for most building situations.

Figure 4. 8: A technician is attaching the data logger to the metallic beam in the atrium space.

4.3.2 Method of Evaluation of Atrium Building Performance

The most common method used to determine the thermal performance of a building, as reviewed from similar studies (Ahmad I. 1985), (Pearlmutter, 1995), (Srivastava, 1984), is the method of comparing the external (ambient) over 24.00 hours temperature to the internal 24.00 hours and the difference in fluctuation is used as a gauge of the thermal performance.

The temperature fluctuation (diurnal range) method will be used in this research because of the high temperature fluctuations experienced in the climate e.g. 22^0C in the cool season and 24.6^0C in the warm season. This method can be used as a guide to how the building performs but it does not give an irrevocable picture on how much the interior conditions vary from the desired thermal conditions. In chapter five, thermal comfort zones will be established for both seasons. However, there is a need to establish a comfort zone based on ambient climatic data for a number of reasons:

1. The comfort zones established in chapter 5 are based on measurements of the *indoor climate* and the survey of the population. Not all the required climatic variables were measured and therefore the thermal comfort zones span are not definitive.
2. The atrium space is more susceptible to ambient climatic changes because:
    - It has a glazed-roof
    - It is not environmentally controlled

Thermal comfort zones based on ambient climatic data were established in chapter 3.

As stated before, the atrium space was monitored for 3 months during the winter (December, January and February) and equal time during the summer period (June, July and August). External climatic data was collected from the Laboratory of Meteorology, Department of Physics, from the University of Ioannina. These two seasons represent the most extreme climatic conditions that can occur. The next step is to select a week for each season for two main reasons:

a. To examine the atrium's performance in context with the local climate

b. The selected climatic data will also be used as an input in the simulation program for the parametric analysis

A week's data was analysed in a graph in order to identify the most "typical day" in terms of ambient temperature for both seasons. It was also considered essential that the days chosen for analysis should be amongst those that the thermal comfort survey took place. Therefore, the results analysed for the survey in the following chapter could be compared with those predicted by the simulation programme. The data collected for the lighting levels inside the atrium space will be used as input for the simulation programme, the results of which are presented in the next chapter.

4.3.3 Cool Season – Measurements, Results and Discussion

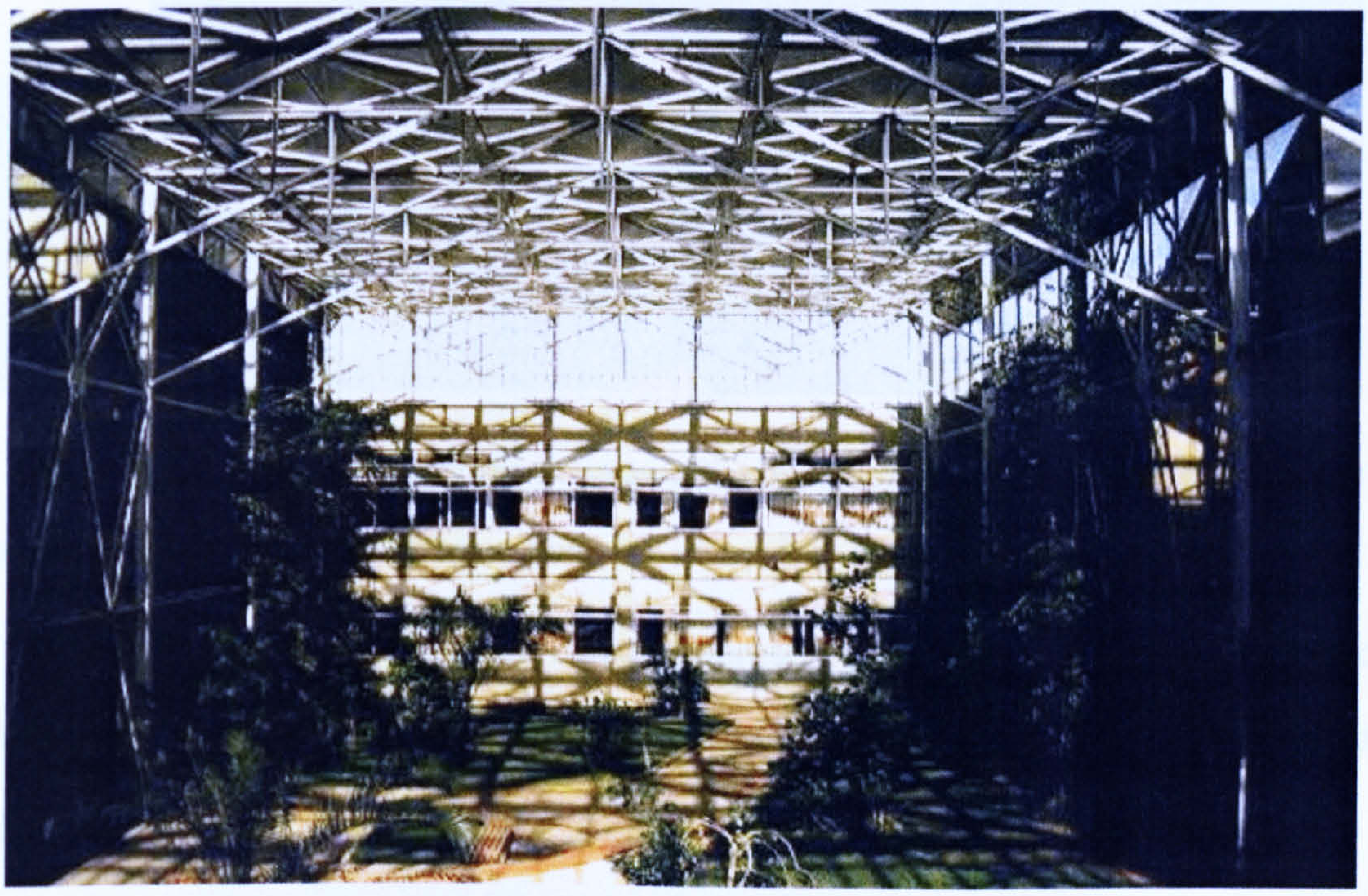

Figure 4. 9: View of the atrium space from the second floor of the south wing in winter

A fundamental aspect of atrium design is orientation to the sun and its effect on building use and occupant comfort. Depending on the orientation, the atrium receives direct sunlight in hugely different amounts from different directions during the day and the season. As it can be seen in Figure 4.9, depending on the north internal façade of the atrium and the floor are exposed to direct sun radiation.

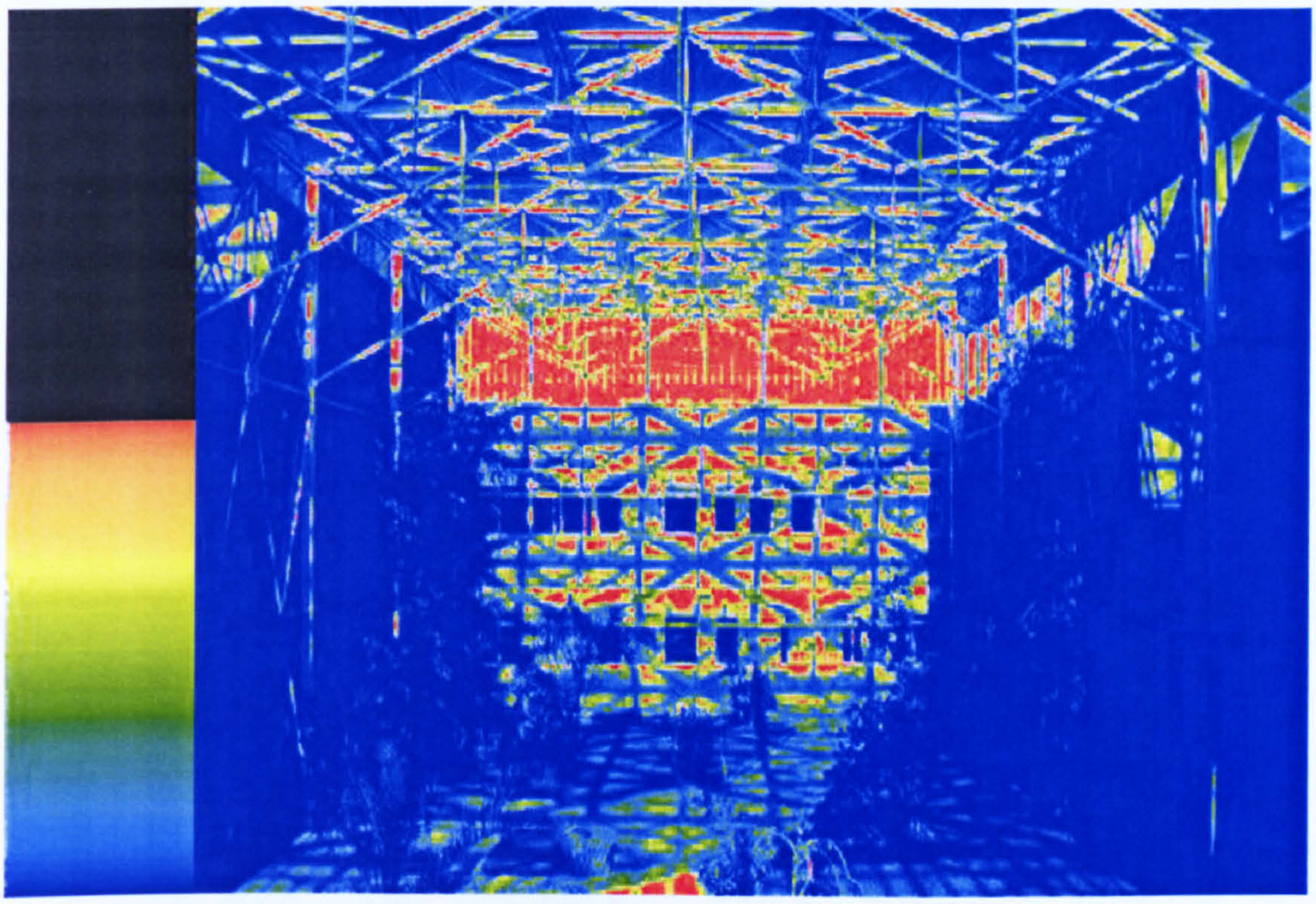

Figure 4. 10: Figure 4.9 with the pseudo-colour representation the image is indicant of the light intensity inside the atrium during winter.

Figure 4.10 shows the pseudo-colour[2] representation image of Figure 4.9, used to show indicatively the light intensity inside the atrium space at 12:00p.m. in a winter day. The technique is used to illustrate the distribution of light incident on the surfaces of a 3D

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[2] Pseudo-colour means that instead of displaying colours in the image based on the wavelength of light reflecting off the surfaces; a colour value is assigned that corresponds to the luminance or illuminance at those pixel locations.

scene. The lighting distribution uses colours ranging from blue to green, yellow, and red. Low values are closer to blue and high values are closer to red.

As it can be seen from the image, the facades of the adjacent building are shaded and represented with the blue colour of the scale. The highest light intensity zones are those indicated by the transparent or semi-transparent elements of the atrium roof, as well as the rays of the direct solar radiation inside the atrium.

Figure 4.11 is an indicator of the two climatic variables recorded inside the atrium in winter months. Plotted out as a two-axis graph, the left axis shows the air temperature and the right axis the relative humidity recorded inside the atrium over a one-month period during the cool season. As it can be seen from the graph, the air temperature fluctuates between 1^0C and 16 ^{0}C with an average temperature of approximately 10^0C whereas the relative humidity levels fluctuate from 25% to 95%.

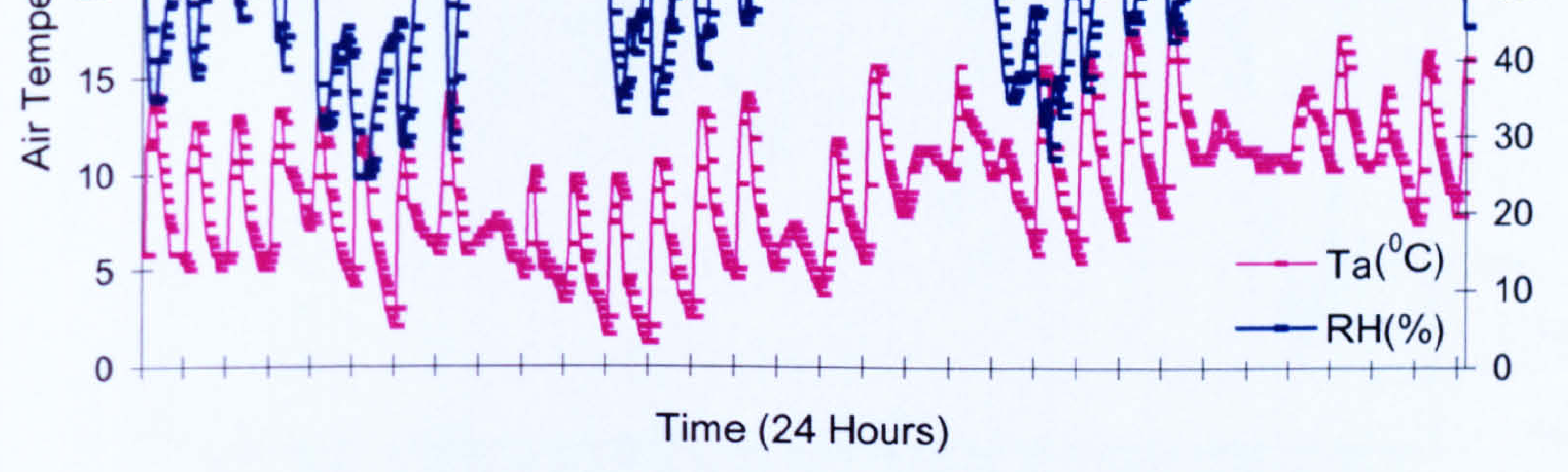


Figure 4. 11: Plot of air temperature and RH inside the atrium for one-month period in the cool season

Figure 4.12 shows the atrium and outdoor air temperature over the one-week selected period. The internal and external temperatures of one week were plotted in order to establish the trend of the temperature over a period longer than 24 hours. As indicated by the graph, the internal atrium temperature is following the pattern of the ambient temperature i.e. the lowest and peak temperatures occur in the atrium in accordance to the lowest and peak outdoors temperatures. That was probable, as it was discussed in the previous chapter, since the atrium space is not environmentally controlled. Additionally, the large glazed area is exposed and more vulnerable to any external climatic change. It can also be seen that the atrium has an average of $5C^0$ higher temperature from the outdoor temperature, especially during the early morning hours when the lowest temperatures occur.

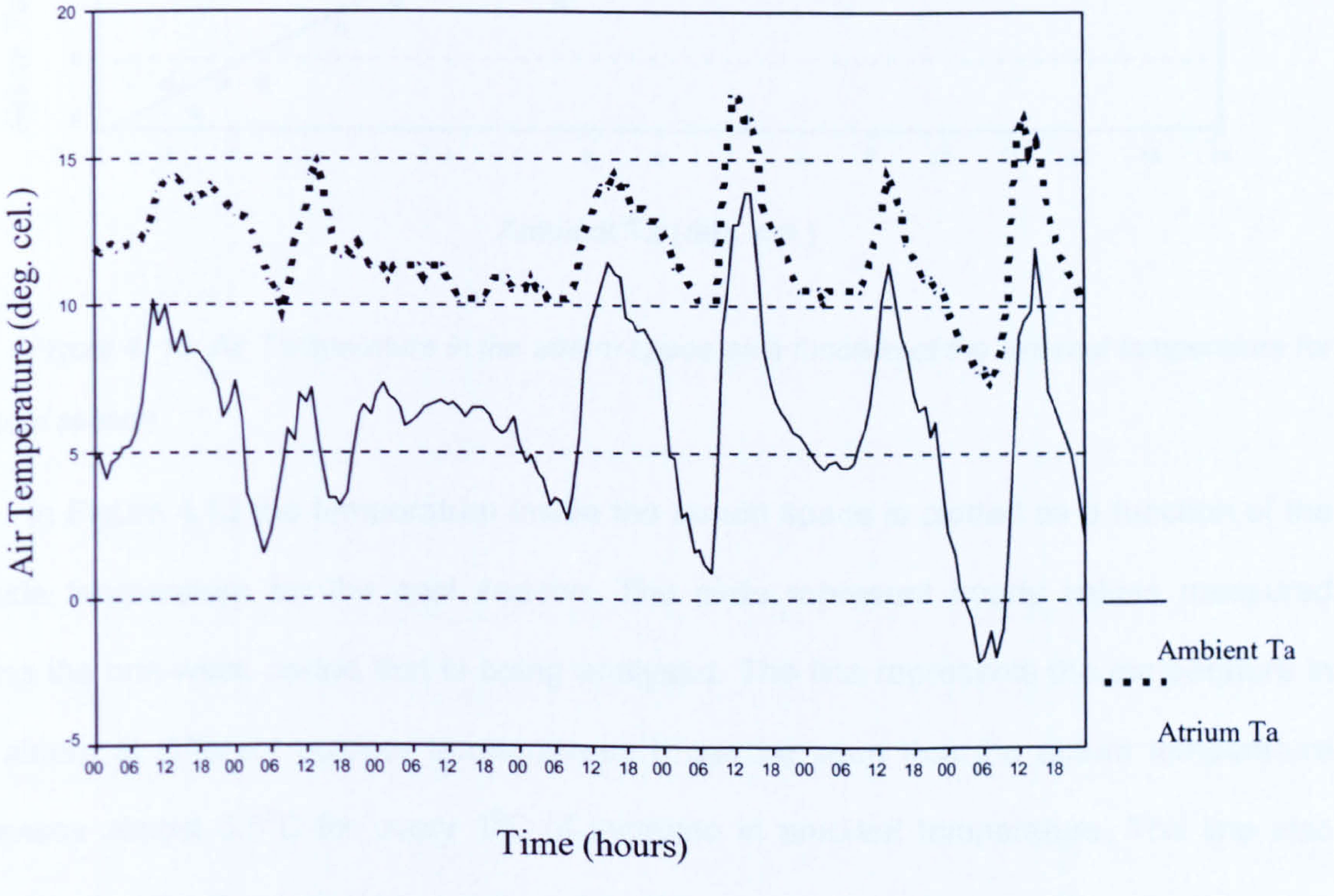


Figure 4. 12: The internal and external air temperature for the atrium building over the one-week period of measurement during the cool season.

During the winter months the aim is to keep the temperature level in the atrium space as high as possible. What mainly determines this temperature level is the relationship between the specific losses and the energy gains in the glazed space as well as the proportion of the glazed space, which is glazed and can let in solar energy (Wall 1996).

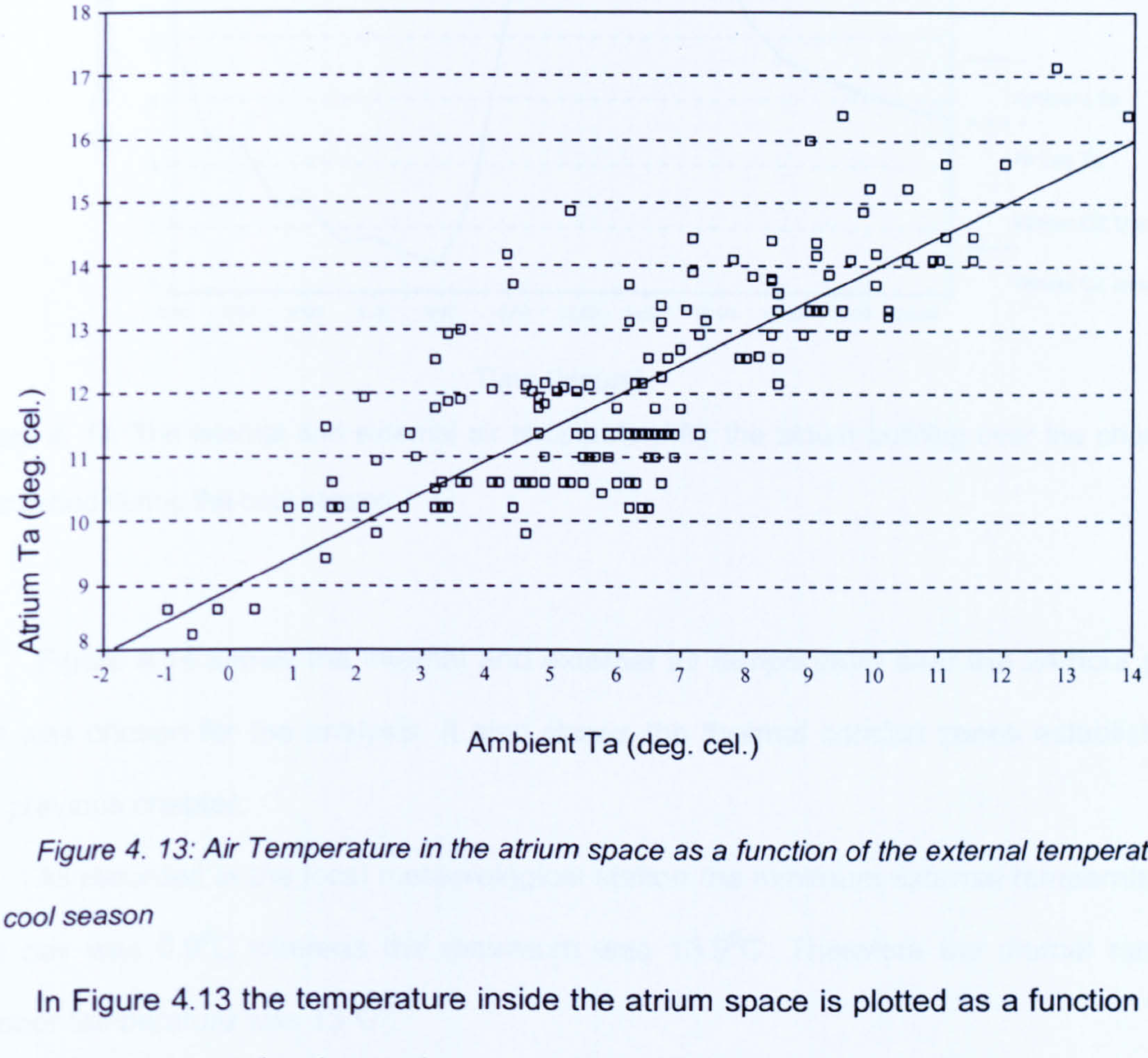


Figure 4. 13: Air Temperature in the atrium space as a function of the external temperature for the cool season

In Figure 4.13 the temperature inside the atrium space is plotted as a function of the outside temperature for the cool season. The plots represent hourly values measured during the one-week period that is being analysed. The line represents the temperature in the atrium at different outdoor temperatures It can be seen that the atrium temperature increases almost 0.5^{0}C for every 1^{0}C of increase in ambient temperature. The line also indicates that the theoretical temperature the atrium and ambient temperature are the same is 18^{0}C.

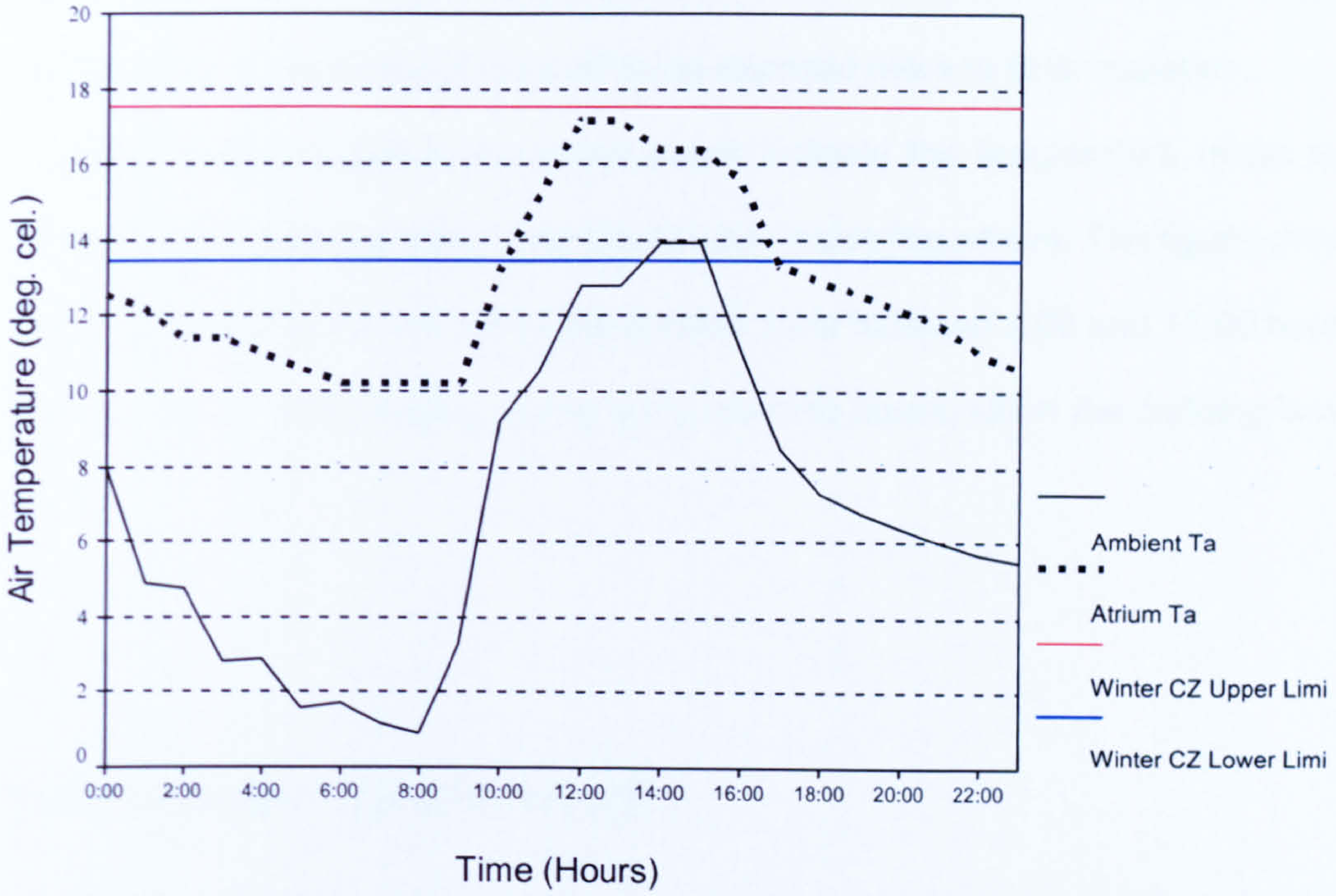


Figure 4. 14: The internal and external air temperature for the atrium building over the chosen 24 hour period during the cool season

Figure 4.14 shows the internal and external air temperature over the 24-hour period that was chosen for the analysis. It also shows the thermal comfort zones established in the previous chapter.

As recorded in the local meteorological station the minimum external temperature for that day was 0.9^0C whereas the maximum was 13.9^0C. Therefore the diurnal range of outdoor temperature was 13 C^0.

The minimum atrium temperature was 10.21^0C and the maximum 17.14^0C and the diurnal range was 6.93 C^0. In average, the atrium was 7.5C^0 warmer than the external environment. Interestingly enough, the maximum temperature difference occurs at the times where there is the lowest ambient temperature. That indicates that the heat losses from atrium space are influenced by the building's thermal mass and therefore cooling happens with a slower pace than in the ambient environment .It can also be seen that the temperature inside the atrium rises sharply between 09.00 and reaches it's peak at 12.00 hours, confirming that it's because of the roof being exposed more to solar radiation.

The comfort zones plotted in the same graph indicate the temperature range that 90% of the occupants surveyed would feel comfortable inside the atrium. The figure shows that the atrium air temperature was within the comfort zone between 9.00 and 17.00 hours. The problem is thus of under heating during early morning hours, when the building is not occupied.

4.3.4 Warm Season - Measurements

The monitoring for the warm season took place in June/July/ August 2000. The format of discussion is the same as used in the cool season and the results are discussed below.

Figure 4. 15: View of the atrium space from the second floor of the south wing in summer

Figure 4.15 shows the view of the atrium space from the second floor of the south wing during the warm season survey. The summer sun is at higher angle and the light is distributed more evenly inside the atrium space. This is also indicated in Figure 4.16 with the pseudo-colour representation the image is indicant of the light intensity inside the atrium during summer where there are only patterns of lines of direct solar radiation on the atrium walls and floor.

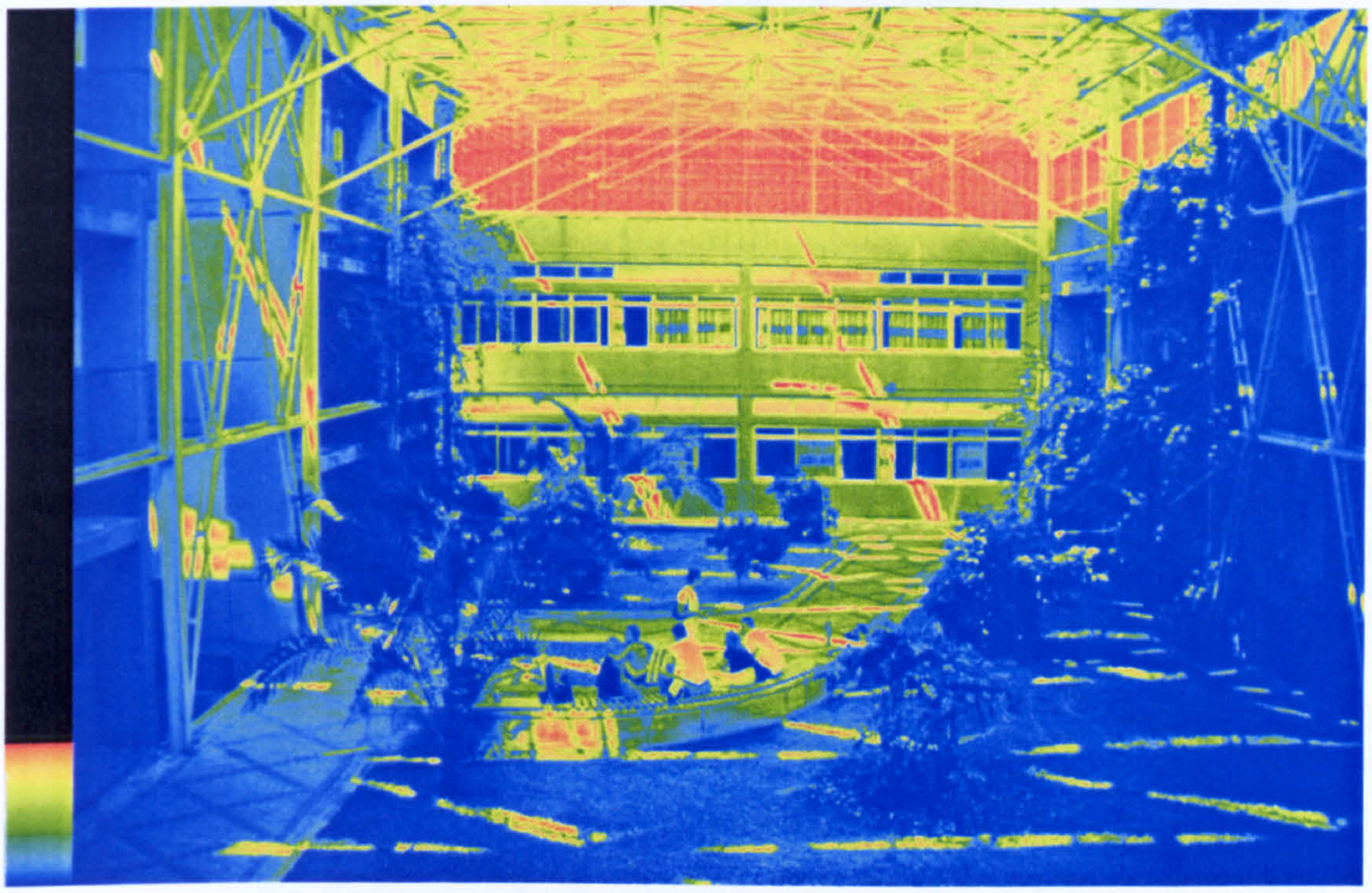


Figure 4. 16: Figure 4.15 with the pseudo-colour representation the image is indicant of the light intensity inside the atrium during summer.

Figure 4.17 is used again as an indicator of the two climatic variables recorded inside the atrium in the summer months. The left axis shows the air temperature and the right axis the relative humidity recorded inside the atrium over a one-month period during the warm season. As it can be seen from the graph, the air temperature fluctuates between 20^{0}C and 33^{0}C with an average temperature around 26^{0}C whereas the relative humidity levels fluctuate from 25% up to 80%.

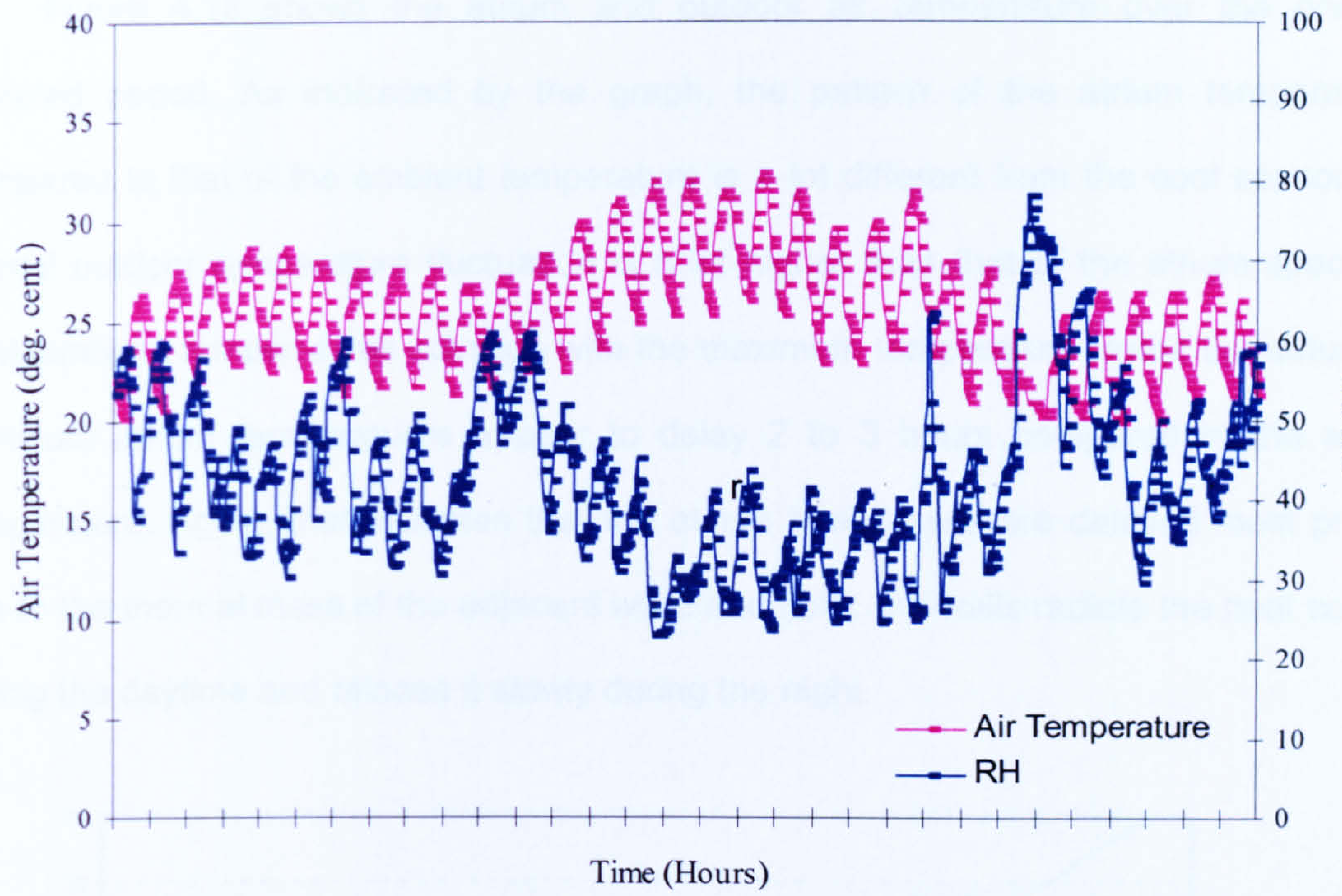


Figure 4. 17: Plot of air temperature and RH inside the atrium for one-month period in the warm season (15th June-15th July 2000)

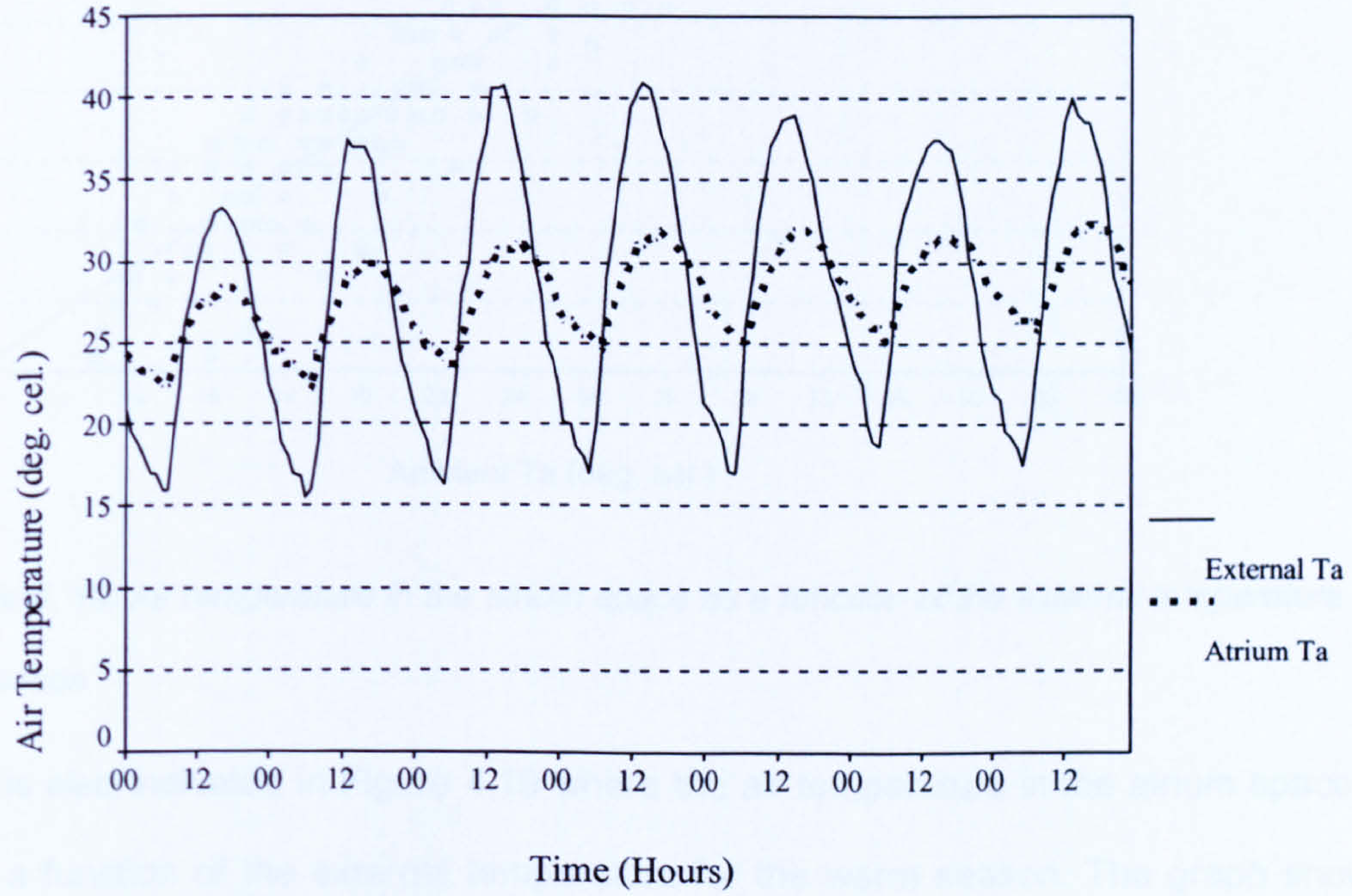


Figure 4. 18: The internal and external air temperature for the atrium building over the one-week period of measurement during the warm season.

Figure 4.18 shows the atrium and outdoor air temperature over the one-week selected period. As indicated by the graph, the pattern of the atrium temperature is compared to that of the ambient temperature is a lot different from the cool season. The diurnal outdoor temperature fluctuation is a lot higher than that of the atrium space. The peak ambient temperatures coincide with the maximum temperature inside the atrium. The minimum atrium temperatures appear to delay 2 to 3 hours compared to the ambient temperature. Again, that indicates that the atrium heat losses are delayed most probably due to the thermal mass of the adjacent walls and floor: the walls radiate the heat collected during the daytime and release it slowly during the night.

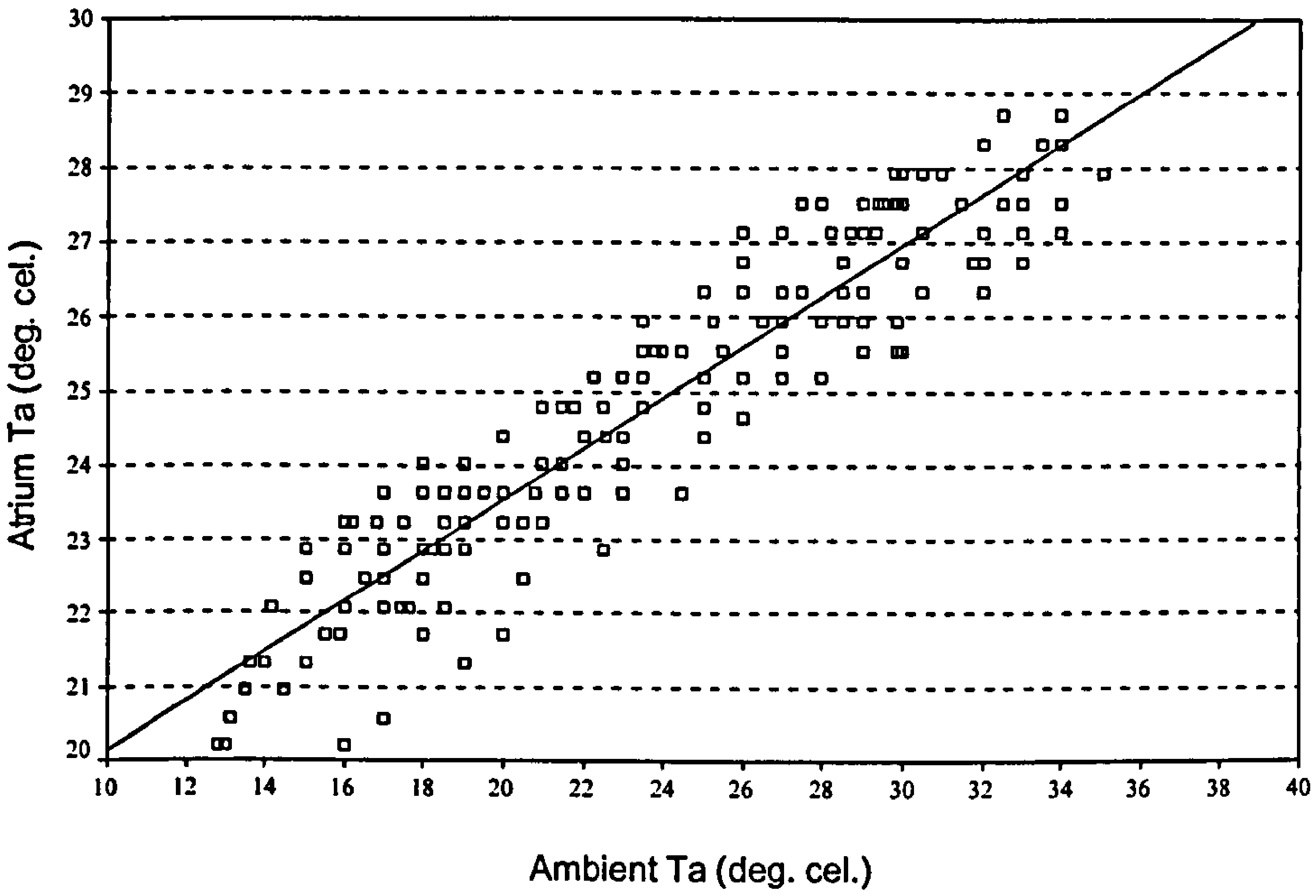


Figure 4. 19: Air temperature in the atrium space as a function of the external temperature for the warm season

This is also indicated in Figure 4.19 where the air temperature in the atrium space is plotted as a function of the external temperature for the warm season. The graph shows that rise of outdoor temperature much less effect on the rise of the atrium temperature.

Figure 4.20 shows the internal and external air temperature over the 24-hour period that was chosen for the period. It also shows the thermal comfort zones established in the previous chapter. As recorded in the local meteorological station the minimum external temperature for that day was 13.7^{0}C whereas the maximum was 34^{0}C. Therefore the diurnal range of outdoor temperature was 20.3C^0.

The minimum atrium temperature was 20.7^{0}C and the maximum 27.5^{0}C and the diurnal range was 6.8C^0. The maximum temperature inside the atrium shifted from 12.00 hours to 20.00 hours. According to Kolsaker (1995), measurements have shown that close to linear temperature profiles are common in atria, mainly due to large hot and cold surfaces.

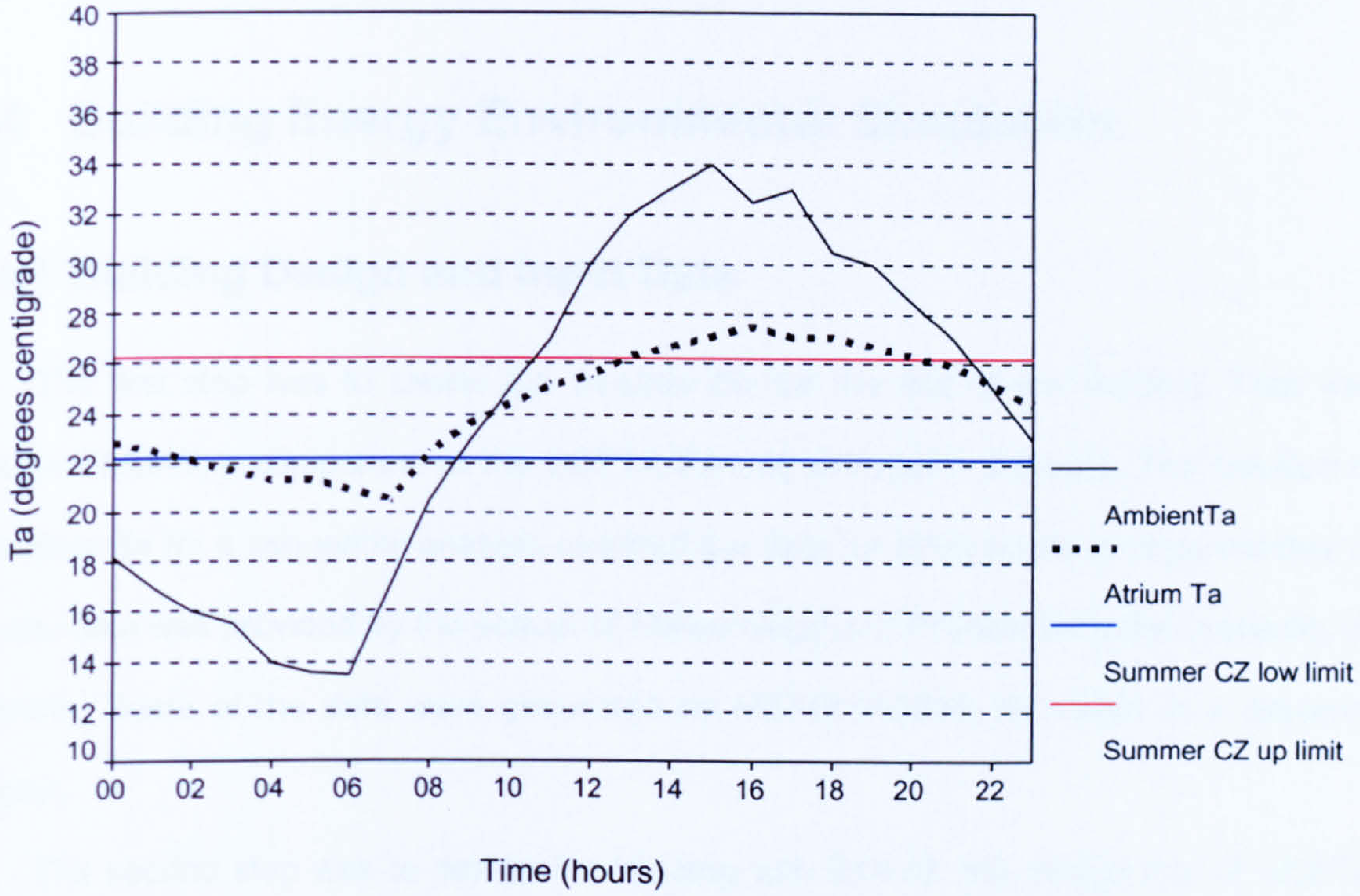


Figure 4. 20: The internal and external air temperature for the atrium building over the chosen 24 hour period during the warm season.

The comfort zones plotted in the same graph indicate the temperature range that 90% of the occupants surveyed would feel comfortable inside the atrium. It can be seen that the atrium air temperature was most of the times within or close to the comfort zone, and lower than the comfort zone, mainly during the early morning hours. The external temperature on the other hand was below the comfort zone from 00.00 to 08.00 hours, and above it from 11.00 to 21.30 hours. Thus, it means that the external conditions are more uncomfortable than the internal conditions. Furthermore, the internal temperature was closer to the comfort zone for most of the day when the shelter from the radiation is needed.

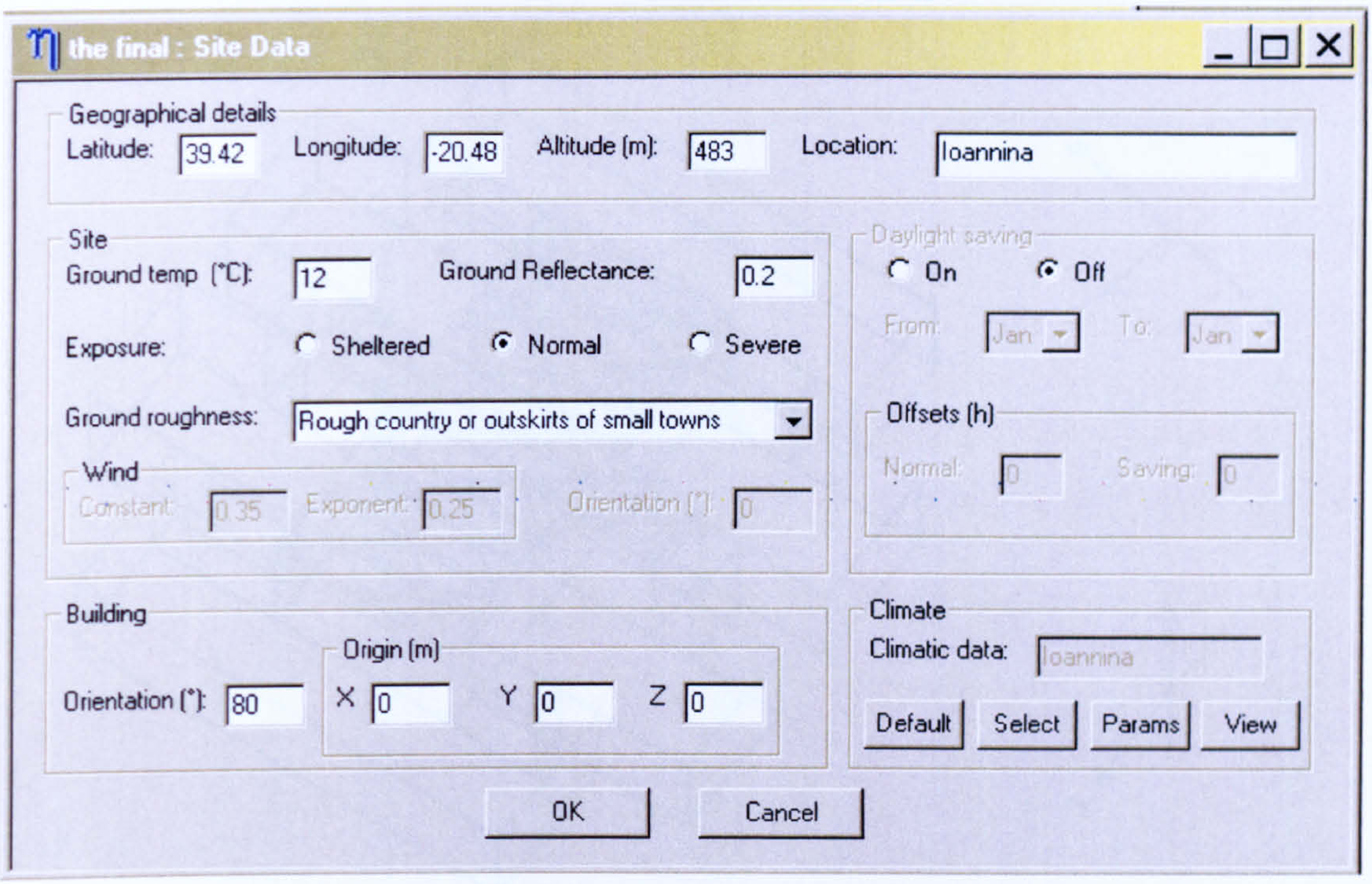
The next part of the chapter focuses on the analysis of the results from the atrium's environmental simulation and the comparison between the measured and predicted data.

4.4 Building Energy Environmental Simulation

4.4.1 Building Design and Input Data

The first step was to create the weather file for the site of the building. That was through CLIDAT, a component of the EDETA thermal simulation software. The creation of a weather file for a sequential analysis required the data for 8760 hours. A large number of climatic data was provided by the school of Meteorology and Physics from the University of Ioannina. Some of the data were generated by METEONORM, as stated in a previous chapter.

The second step was to design the building with ROOM, the design tool of EDETA (full description of the software and its components is given in APPENDIX D). The data required at this first stage was site data as seen in Figure 4.21. That includes the selection of the climatic file, information of the site's ground temperature and ground reflectance, exposure and the building's origin and orientation.



Geographical details
Latitude: 39.42
Longitude: -20.48
Altitude (m): 483
Location: Ioannina

Site
Ground temp (°C): 12
Ground Reflectance: 0.2
Exposure: ○ Sheltered ● Normal ○ Severe
Ground roughness: Rough country or outskirts of small towns

Wind
Constant: 0.35
Exponent: 0.25
Orientation (°): 0

Daylight saving
○ On ● Off
From: Jan
To: Jan

Offsets (h)
Normal: 0
Saving: 0

Building
Orientation (°): 80

Origin (m)
X 0
Y 0
Z 0

Climate
Climatic data: Ioannina

Figure 4. 21: Site data dialog box

The room creation was one of the most challenging parts of the building design and data input. The model of the building designed is shown in Figure 4.22. The atrium roof, described in the beginning of the chapter, consists of a complex design of pyramids. A detail of the roof pyramids is shown in Figure 4.23.

However, problems were encountered during the thermal analysis, and the calculation had to be aborted, as the building was too complex for the analysis.

Further attempts were made with a number of models, by varying the amount of pyramids of the roof, one of which is shown in Figure 4.24. In the stage of the thermal analysis no calculation could be completed.

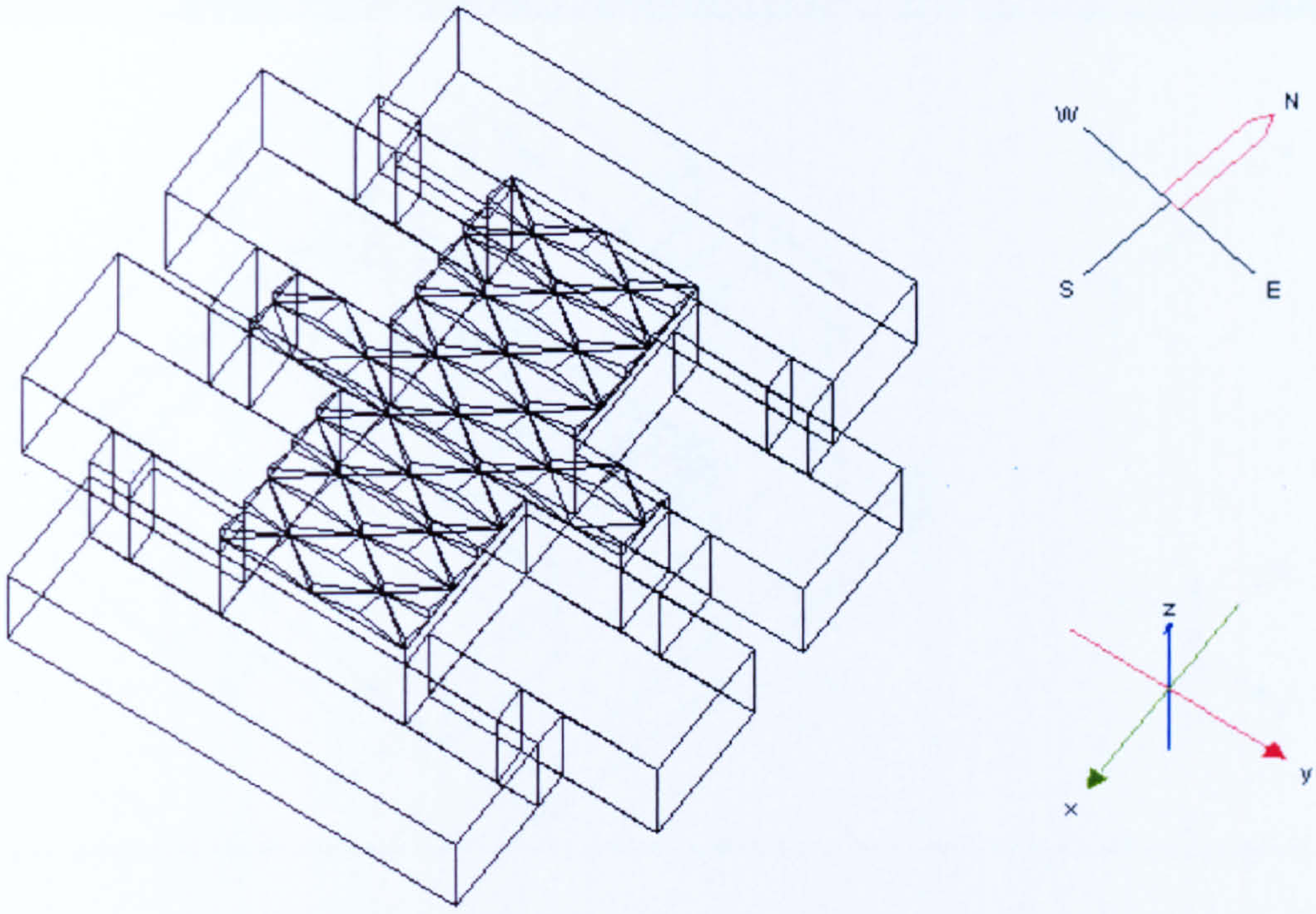


Figure 4. 22: The model of the atrium building with the atrium roof as it is constructed

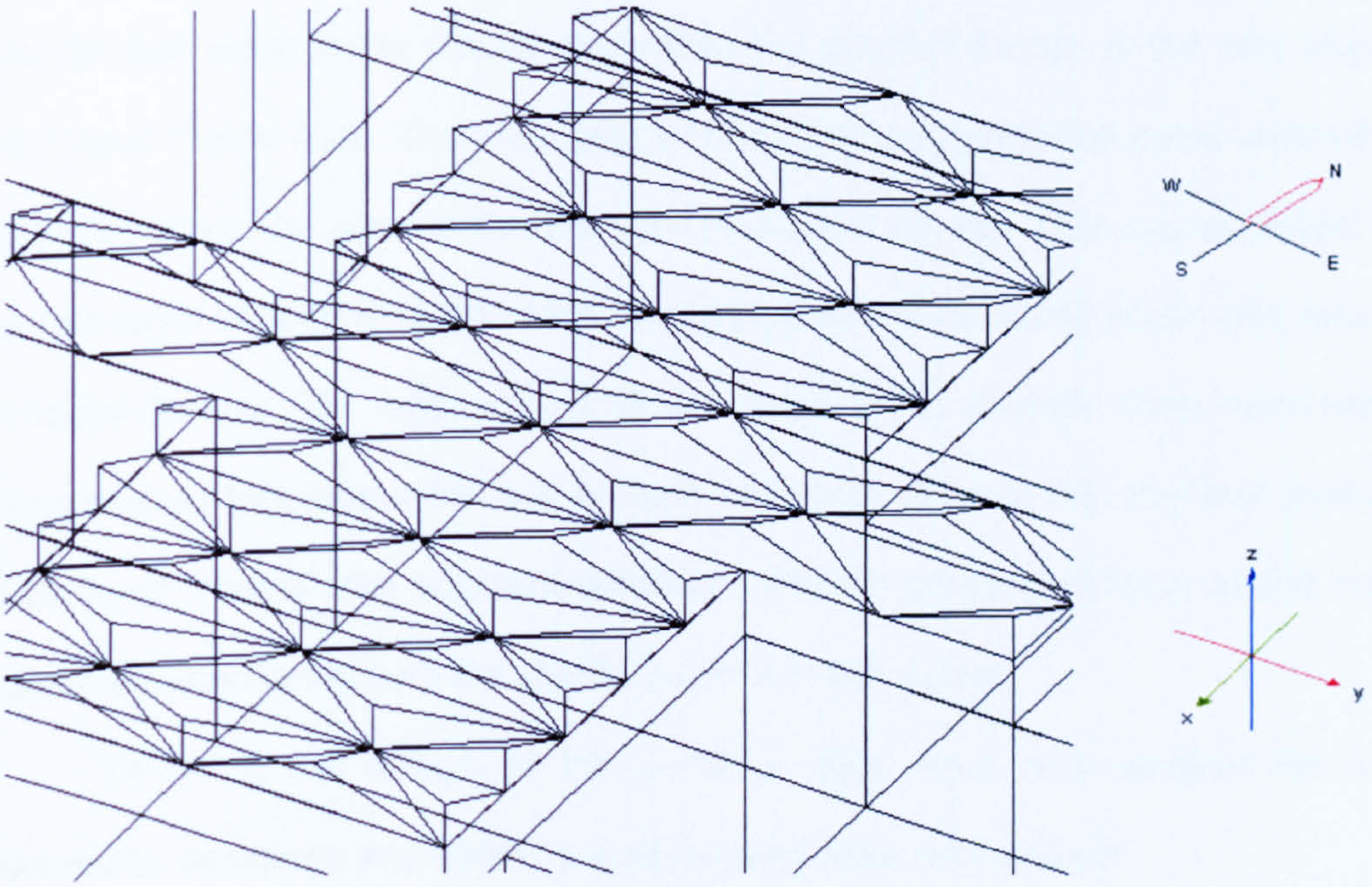


Figure 4. 23: Detail of the pyramids of the atrium roof (original design)

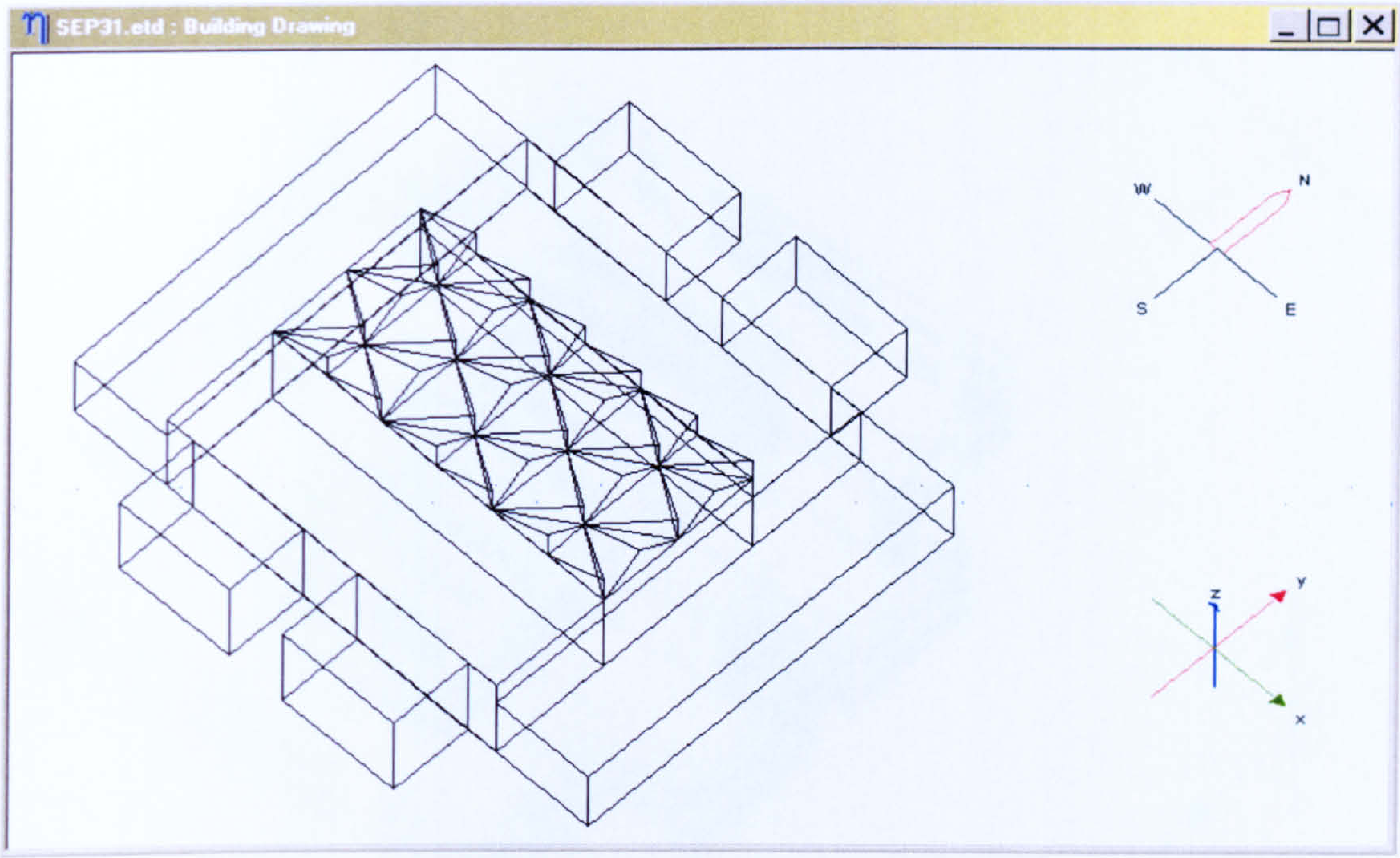


Figure 4. 24: One of the testing models created as a simplified version of the original design.

Therefore a more simplified model had to be created. With aid and advice from the programme developers, and after a large number of test models, it was decided that the model that would most closely assimilate the original design is the one shown in Figure 4.25 and Figure 4.26. The main problem was to incorporate the same amount of glazing in the roof and in the same orientation as the original model. That was achieved by designing a saw-tooth shaped roof that adds the glazing elements facing south very accurately to the original design. The adjacent rooms are designed as a single zone room with a constant temperature throughout the day for both seasons. As a result, the final model consists of two major "rooms": the adjacent buildings, with the same dimension as the original model, and the atrium room, with the slightly modified roof shape.

Following the design of the building, data input was required for the building's elements, apertures and aperture position and room environment.

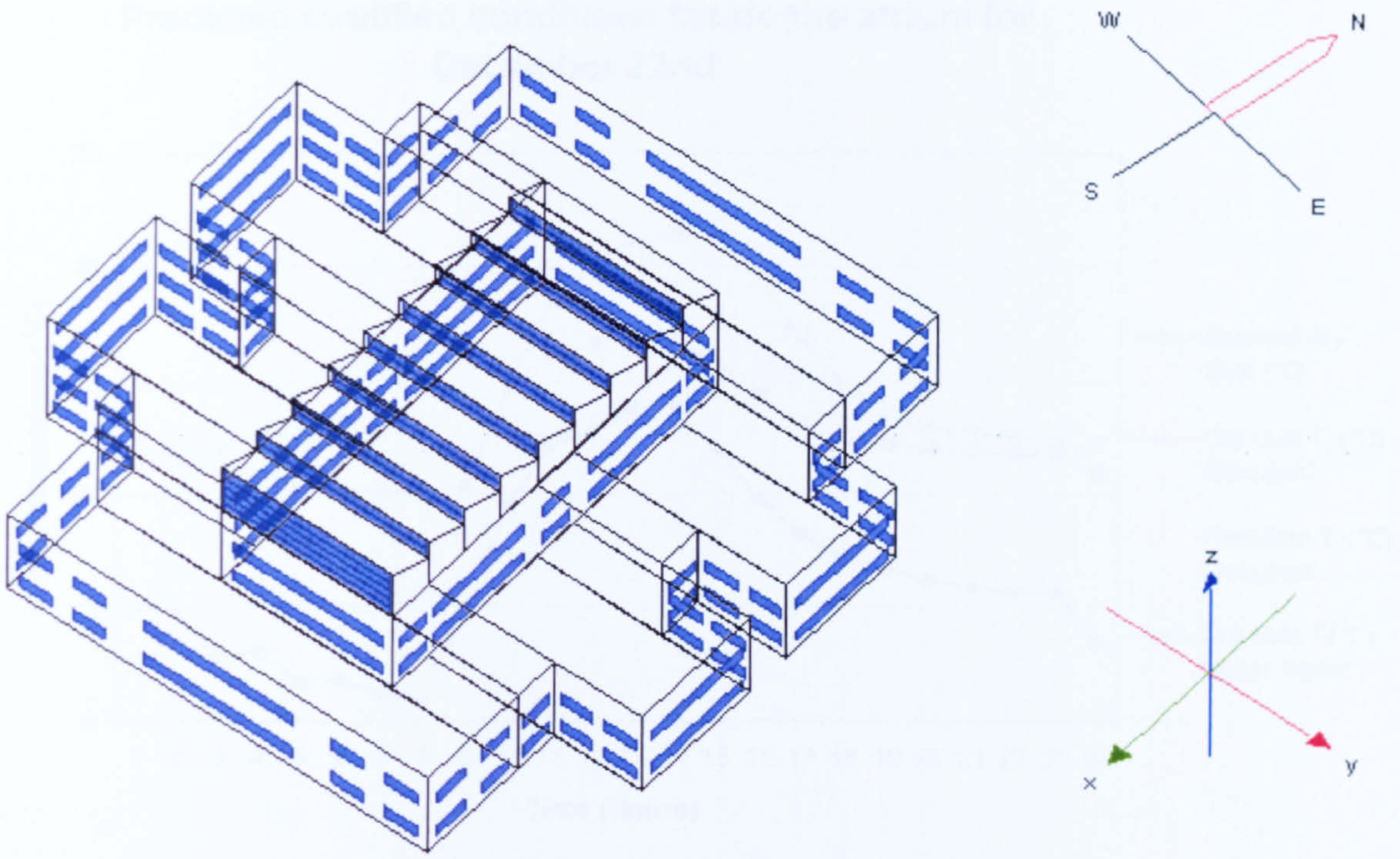


Figure 4. 25: The atrium building model as it is designed due to program's limitations

Figure 4. 26: Perspective of the east façade of the building model

4.4.2 Thermal Simulation Analysis – Cool Season

The next step was to input the required data for use into ROOM programme. For the cool season the day for the sequential analysis was the 22nd of December. For stratified conditions, the results of air temperature inside the atrium in December 22nd are shown in Figure 4.27.

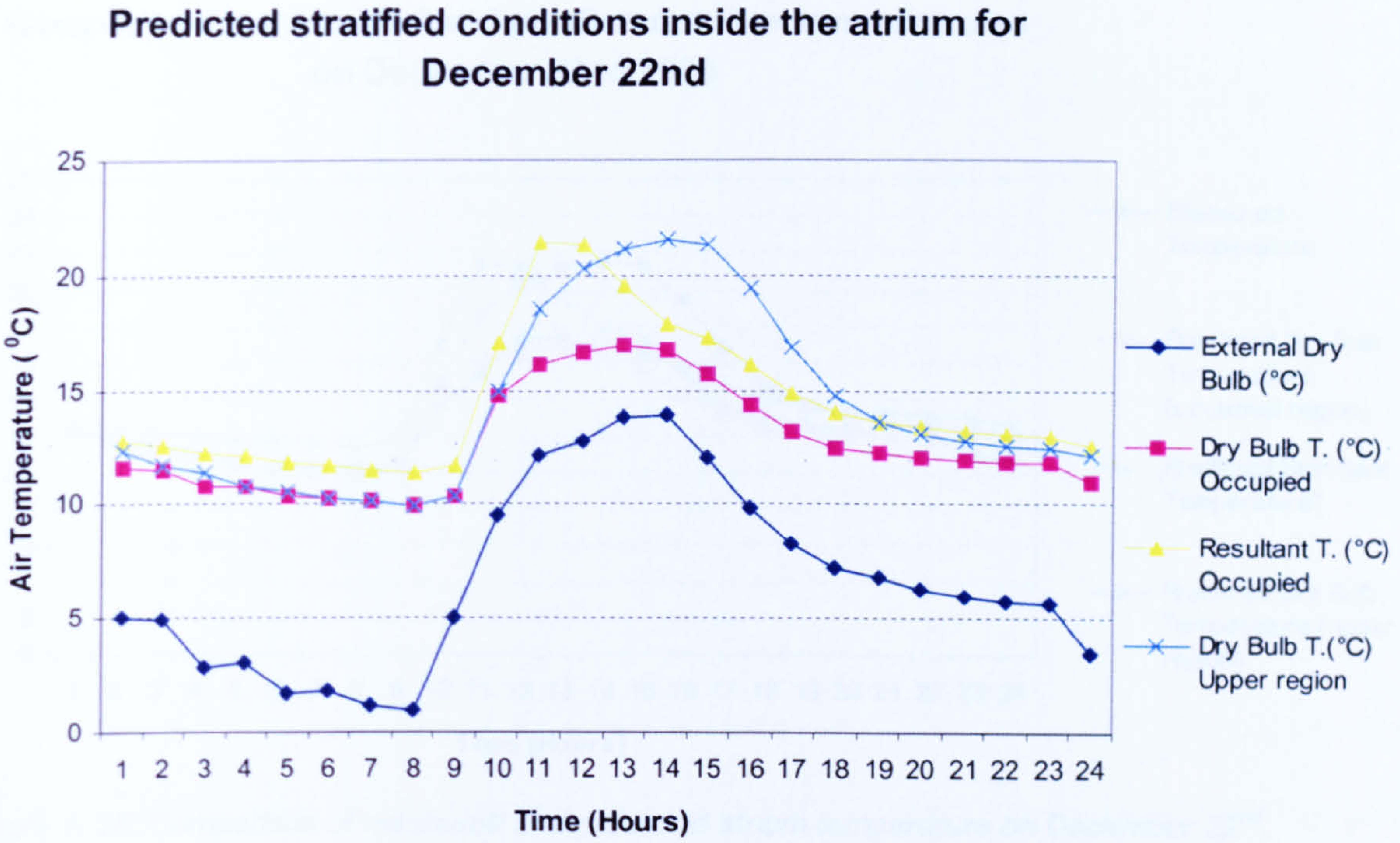


Figure 4. 27: The results of predicted stratified conditions inside the atrium for December 22nd

This method is used to predict an air temperature near the floor and an upper-level air temperature, which indicates the likely temperatures for the rest of the space. The stratified flow model is used in cases where the majority of the occupants are in the shallow zone at the bottom of the room, i.e. an atrium. The flow rate due to natural ventilation only is calculated assuming a zero wind speed and hence is created by stack effect alone.

The graph shows the variation of predicted dry bulb temperature in the occupied and upper region of the atrium as well as the variation of the resultant temperature. The difference in inside air temperature between levels is only 1C ^{0} during the late evening hours, whereas there is much less difference during the late night and early morning hours. During the day, however, the difference between the upper and occupied zone varies by as much as 6C ^{0}.

Figure 4.28 shows the comparison of measured and predicted atrium temperatures on December 22nd.

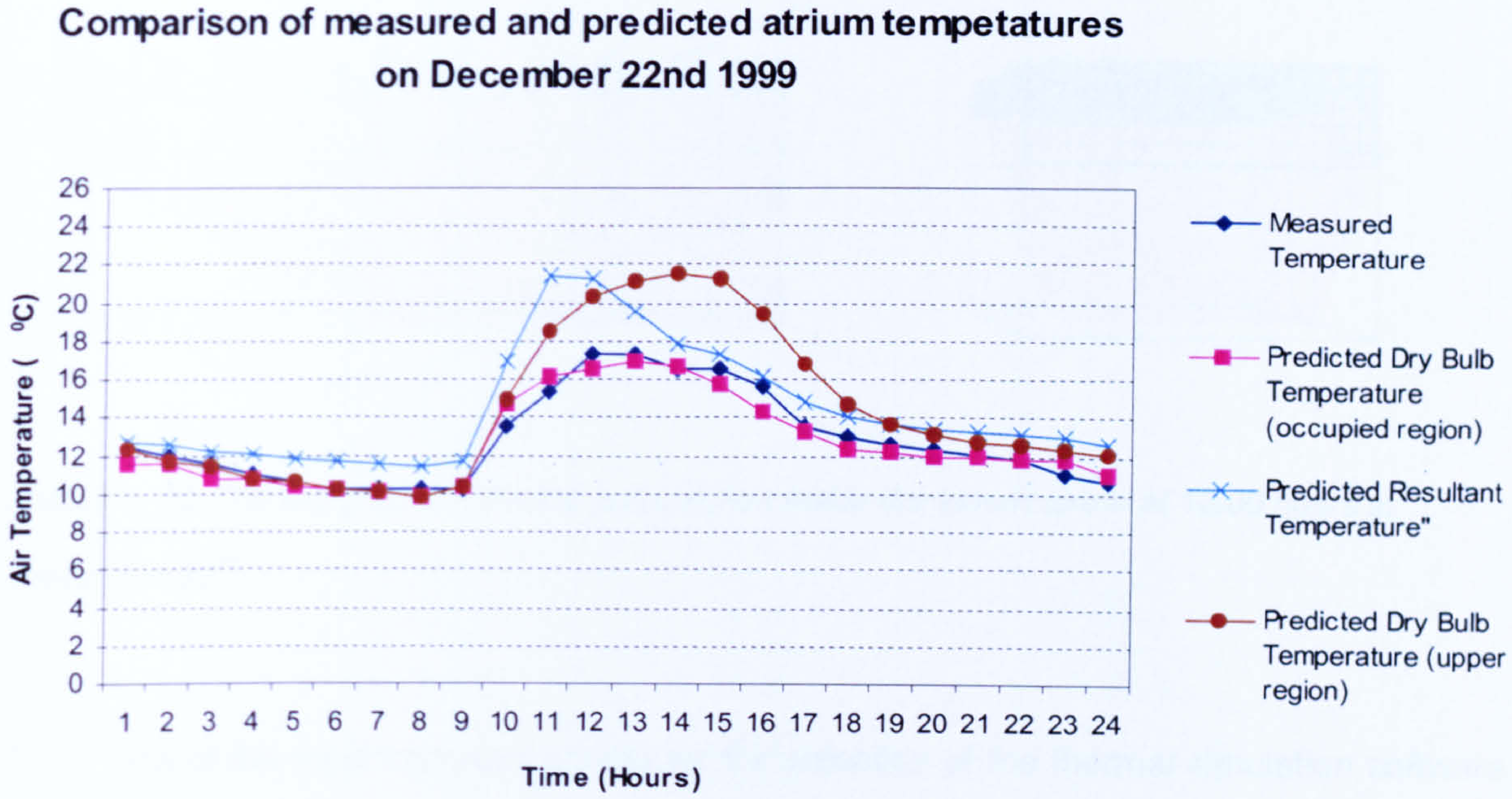


Figure 4. 28: Comparison of measured and predicted atrium temperature on December 22nd.

As it can be seen from the graph the predicted dry bulb temperature is in very good agreement with the measured data probably due to the position of the data loggers (closer to the occupied region). However, according to the measured data, the peak temperature inside the atrium is at 14:00 hours, whereas for the predicted data that is at 12:00 hours. The predicted resultant and dry bulb temperatures of the upper region are also close to the measured data with no more than 2C^0 difference but not for the time period between 9:00 till 17:00 hours. During that period the resultant temperature appears to be up to 3.5^{0}C and the dry bulb temperature for the upper region up to 4^{0}C higher, showing evidence of stratification of air temperature. Therefore for the current study the predicted dry bulb temperature for the occupied region will be used.

The programme is also able to visualize in 3D, for the selected day and hour, the distribution of direct solar radiation within the atrium space. Figure 4.29 shows the sun patches for 12:00 hours on December 22nd.

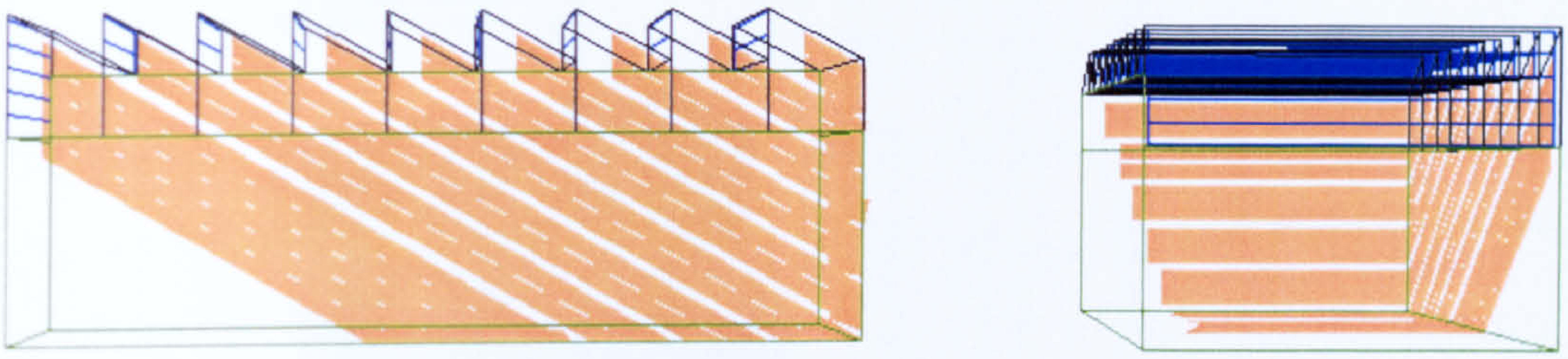


Figure 4. 29: The two graphs show the sun patches inside the atrium space at 12:00 hours in December 22nd.

One of the most important criteria for the selection of the thermal simulation software ROOM, was the ability to analyse and predict thermal comfort conditions. In order to do that, the programme uses the same input data from EDETA and ROOM, and once the thermal analysis of a room is completed then a comfort analysis can be performed.

Figure 4.30 shows the Predicted Percentage of People Dissatisfied in the atrium space at 12 noon in December and Figure 4.31 shows a graphical representation of the PPD for December 22nd. As it can be seen from the graph, the lowest percentage of dissatisfied people coincides with the hours of highest air temperatures inside the atrium. The graph should be examined with the graphs in Figure 4.32, Figure 4.33 and Figure 4.34.

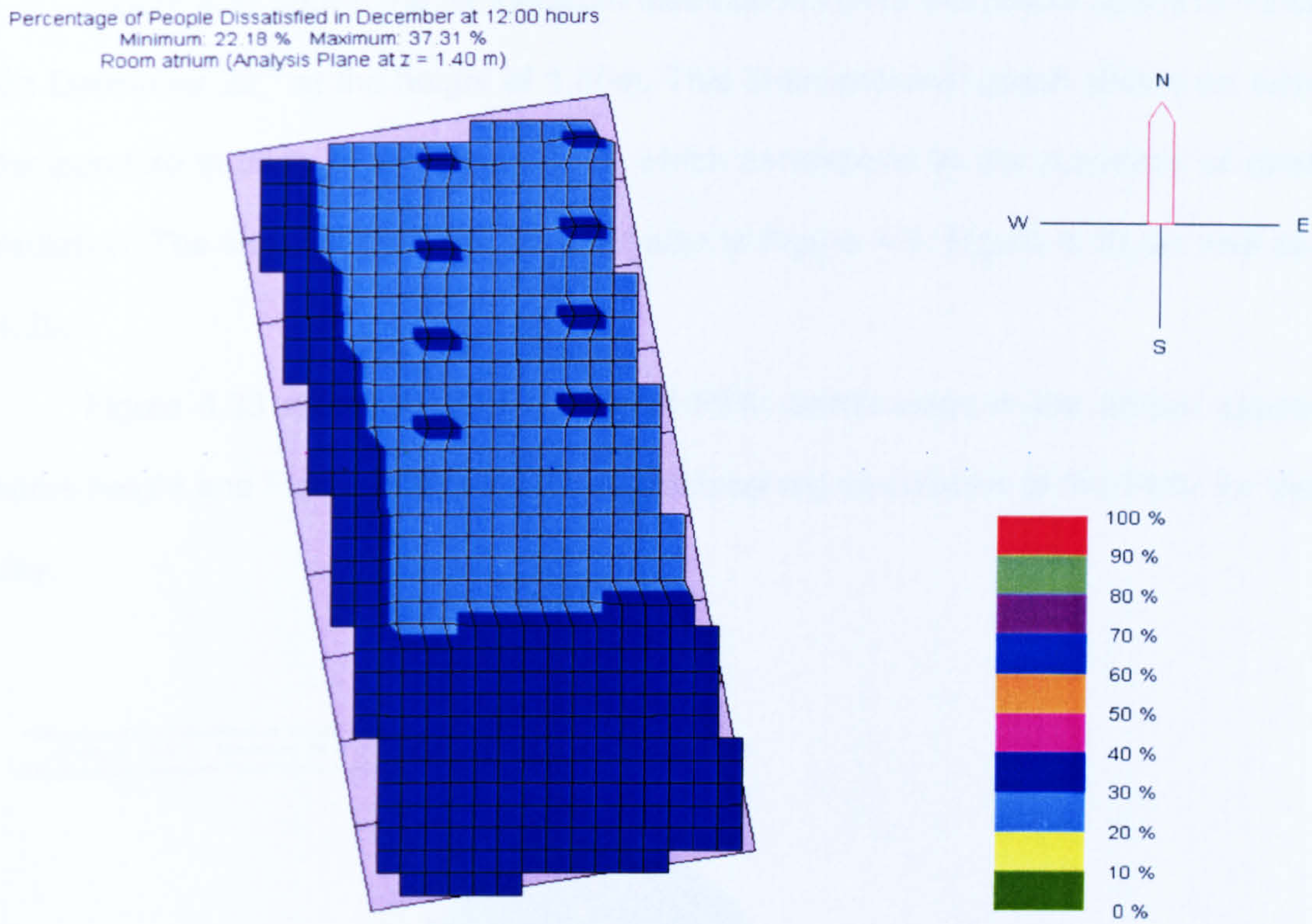


Figure 4. 30: Percentage of People Dissatisfied at 12:00 hours in December

Figure 4. 31: The PPD for the atrium space on December 22^{nd}.

Figure 4.32 shows the temperature distribution inside the atrium space at 12:00 hours on December 22nd at the height of 1.40m. This 3-dimensional graph shows an increase of temperature in parts of the atrium floor, which correspond to the presence of direct solar radiation. The same pattern can be seen also in Figure 4.9, Figure 4.10, as well as Figure 4.29.

Figure 4.33 shows the 3-dimensional PMV distributions in the atrium space at the same height and Figure 4.34 shows the graphical representation of the PMV for the whole day.

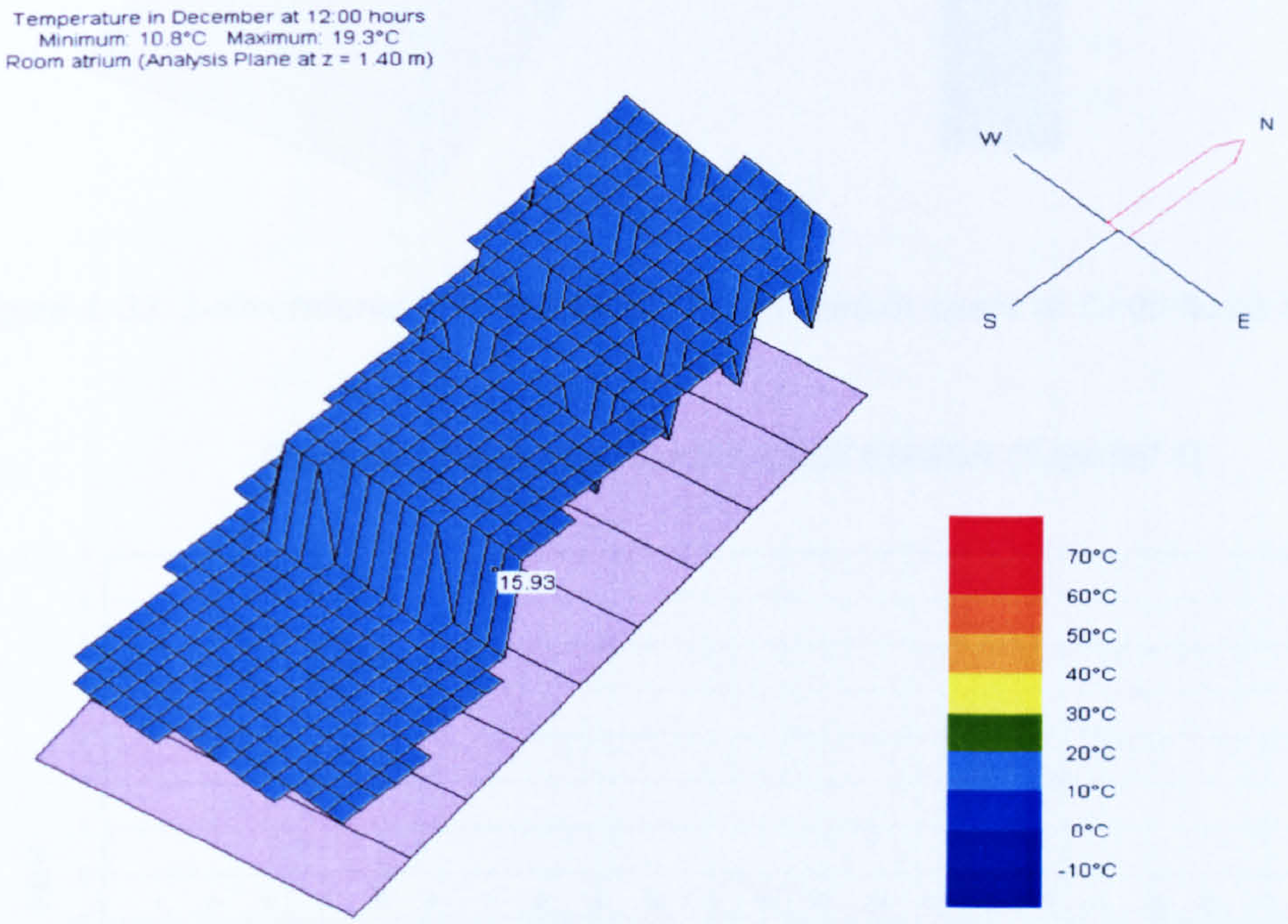


Figure 4. 32: Representation of temperature distribution inside the atrium space at 12:00 hours on December 22nd.

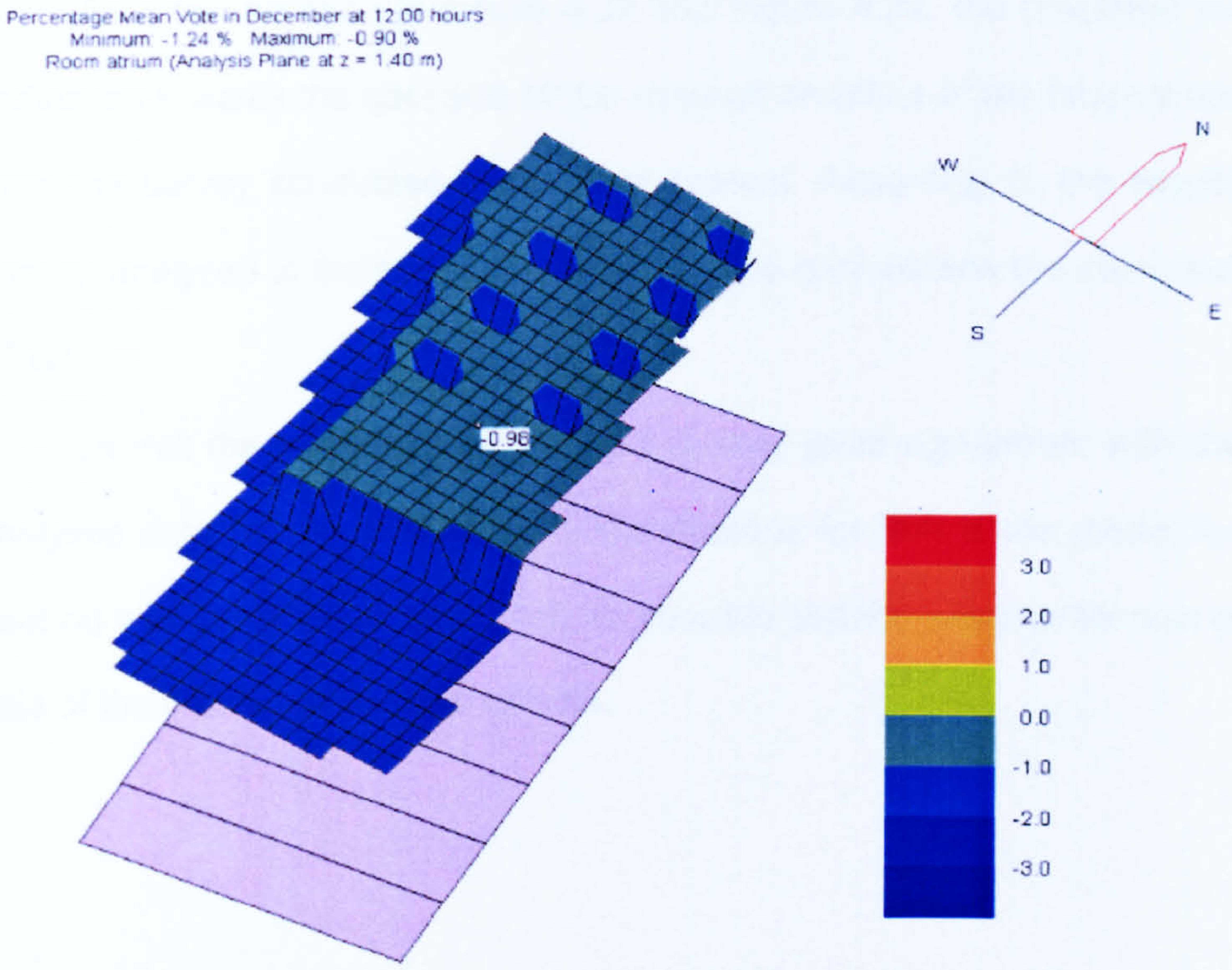


Figure 4. 33: 3-dimensional PMV distributions in the atrium space at 12:00 hours on December 22nd

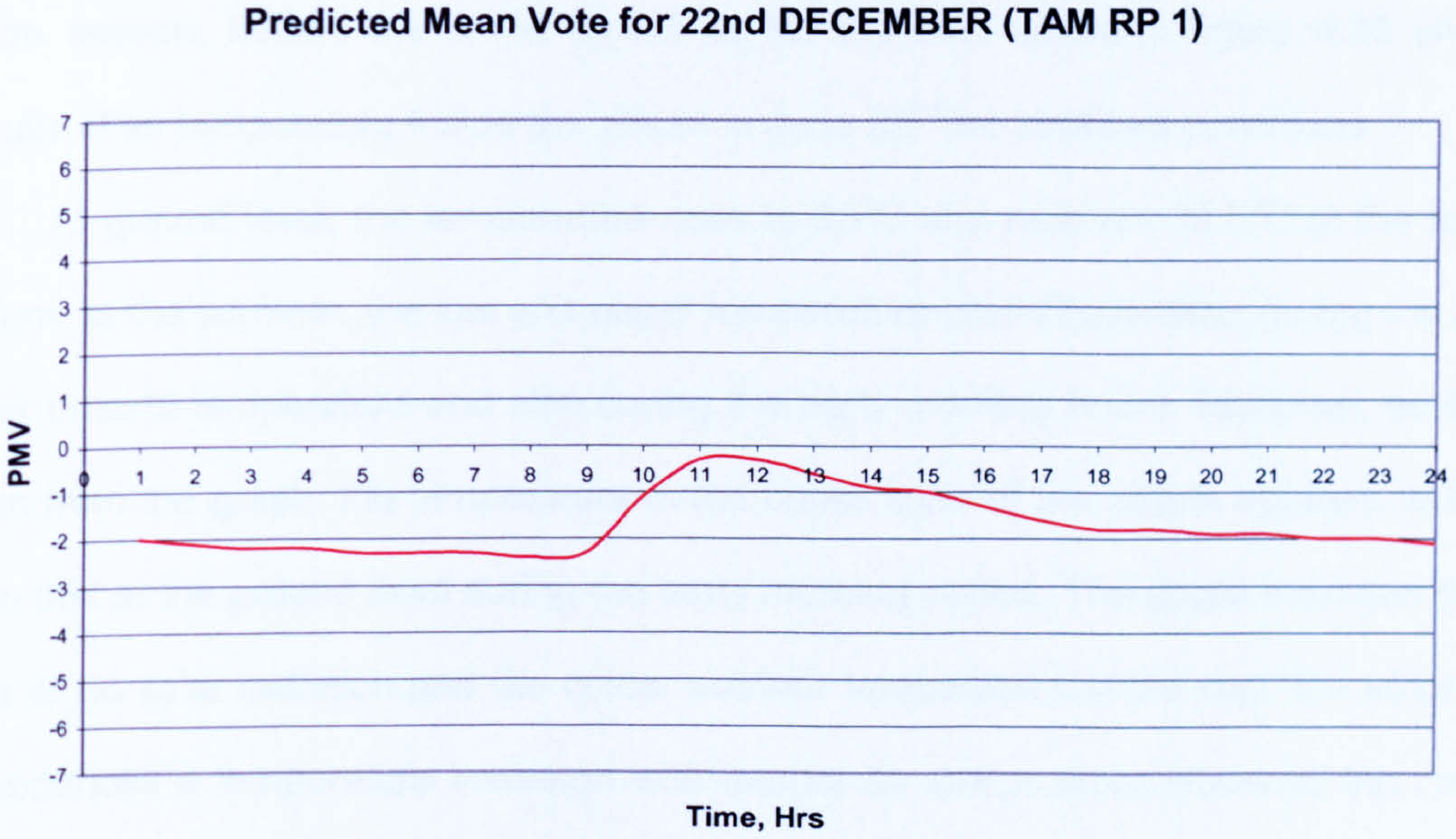


Figure 4. 34: Predicted Mean Vote for December 22^{nd}

As it can be seen in Figure 4.33 and Figure 4.34, the predicted mean vote has an inclination towards the cool side of the scale as an effect of the internal conditions resulting from the survey conducted in the cool season. According to the results of the comfort survey, analysed in the previous chapter, for the cool season the mean sensation vote was –0.58.

Overall the predicted results were in very good agreement with the measured and analysed data for the cool season. The reasons for that is the model for the case study building was designed as accurately as possible and the weather file was common from the data of the measured ambient climate.

4.4.3 Thermal Simulation Analysis – Warm Season

The analysis of the results predicted by the thermal simulation programme for the warm season, follows the same format as for the cool season. Figure 4.35 shows the results of air temperature inside the atrium in June 22nd for stratified conditions.

At ground level, the temperature rises to 28^{0}C and reaches 30.5^{0}C at the top of the atrium. In the summer, the low and upper temperature predictions differ during the hours of peak outside temperature and also during the early morning hours. However, as it can be seen from the graph, the temperature in the upper zone of the atrium appears to be lower than that at the ground level during the early morning period. The graph indicates that, with little or no solar radiation and the colder outdoor temperature of the day, the atrium space experiences a temperature inversion with interior air temperature closer to the roof lower than that at the floor. This could be attributed to the thermal mass effect of the parent to the atrium buildings.

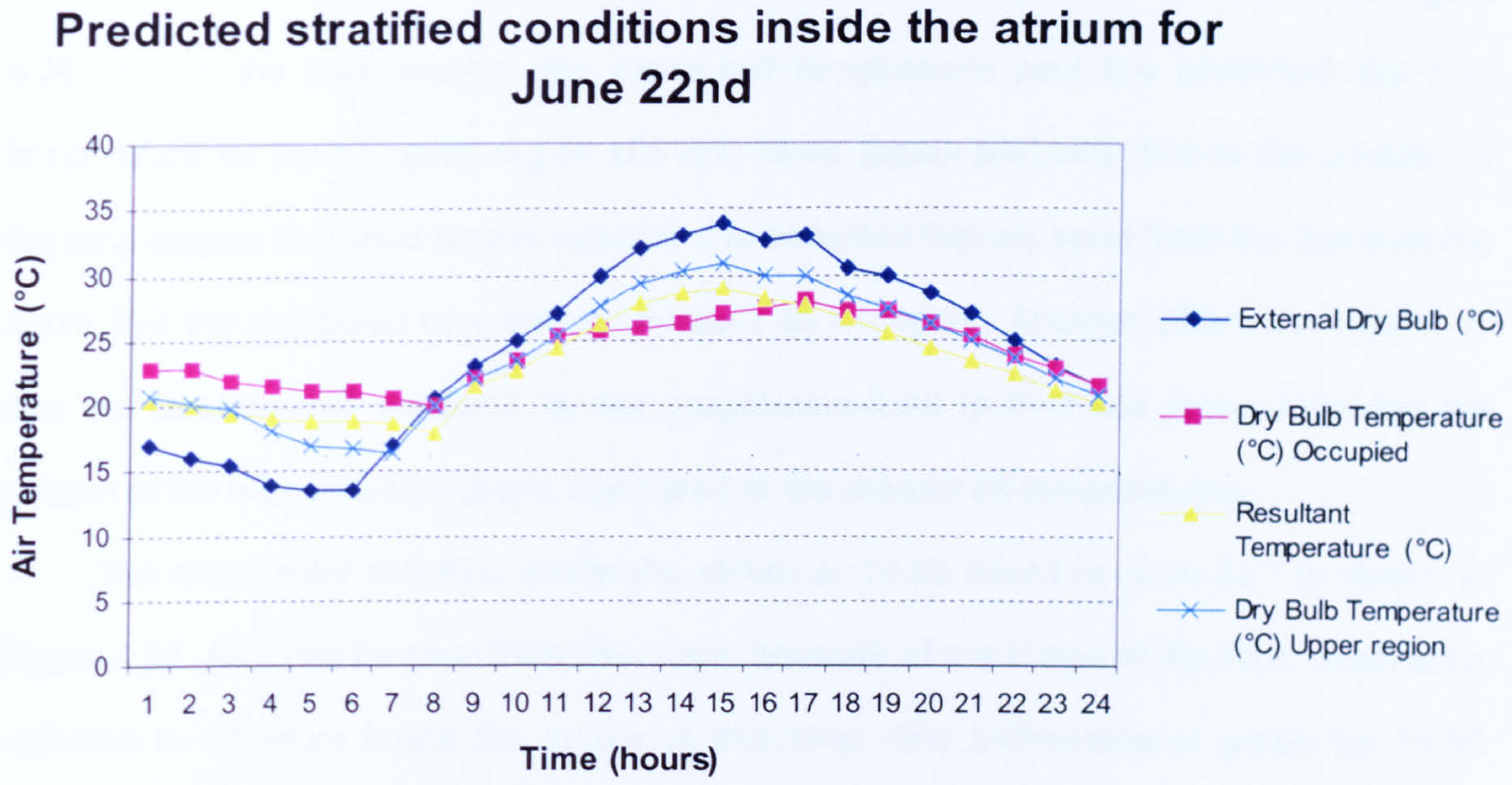


Figure 4. 35: The results of predicted stratified conditions inside the atrium for June 22nd

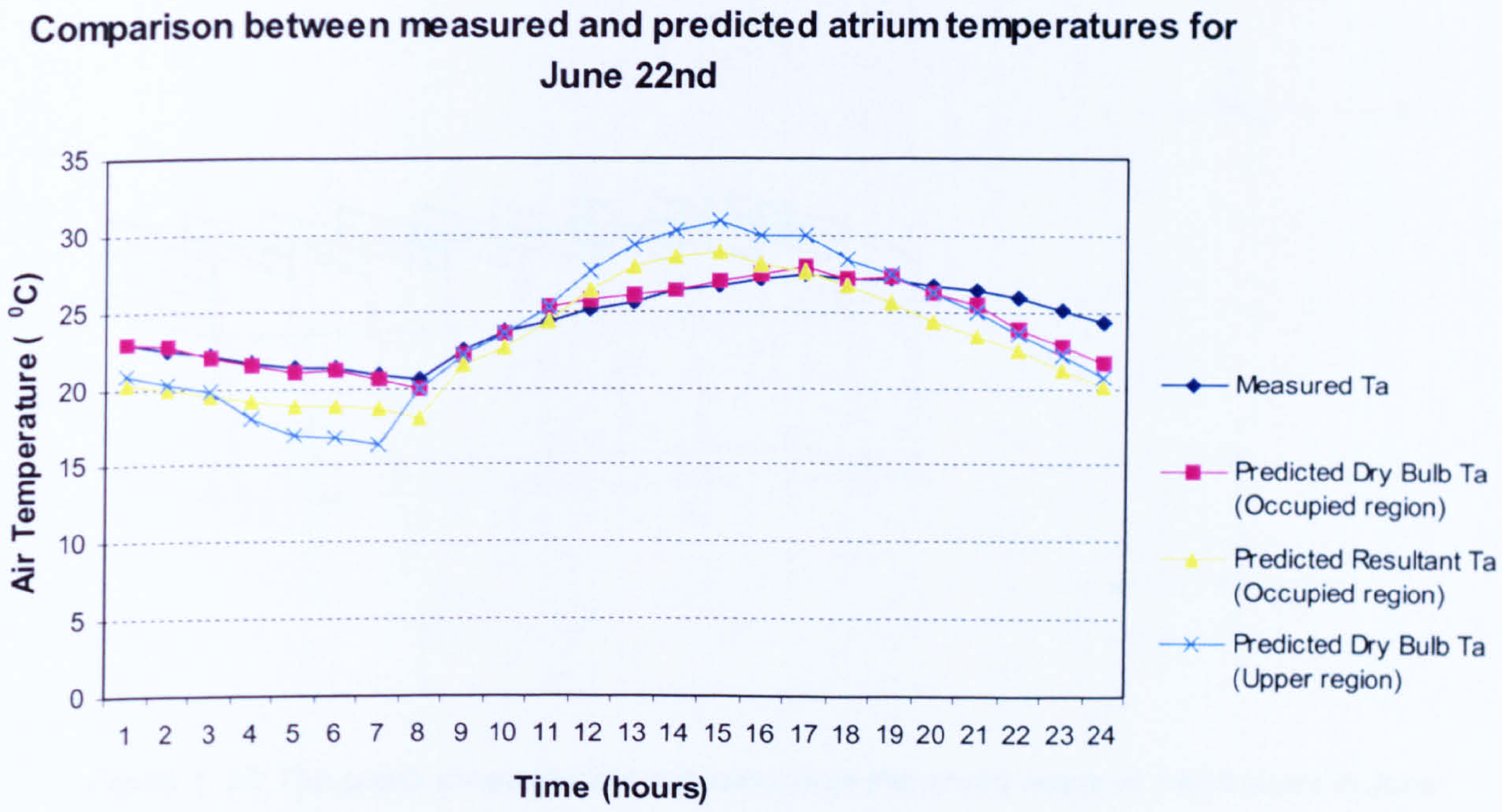


Figure 4. 36: Comparison of measured and predicted atrium temperature on June 22nd.

Comparison of the measured and predicted data for June 22nd is shown in Figure 4.36. As for the cool season, the measured temperature and the predicted dry bulb temperature for the occupied region are very close (again probably due to the position of the data loggers that were placed closer to the occupied region) apart from the late evening hours that the measured temperature appears to be higher. Another difference noticed is that the temperatures predicted by the programme tend to fluctuate more, following the pattern of the outside temperature, compared to the measured temperatures.

The direct solar radiation inside the atrium at 14:00 hours in June 22nd is shown in Figure 4.37. As it can be seen from the graph, because of the shape of the roof, direct solar radiation is minimum inside the atrium at that time. The 3-dimensional graph for 15:00 hours show no direct solar radiation inside the atrium space when there is peak outside temperature.

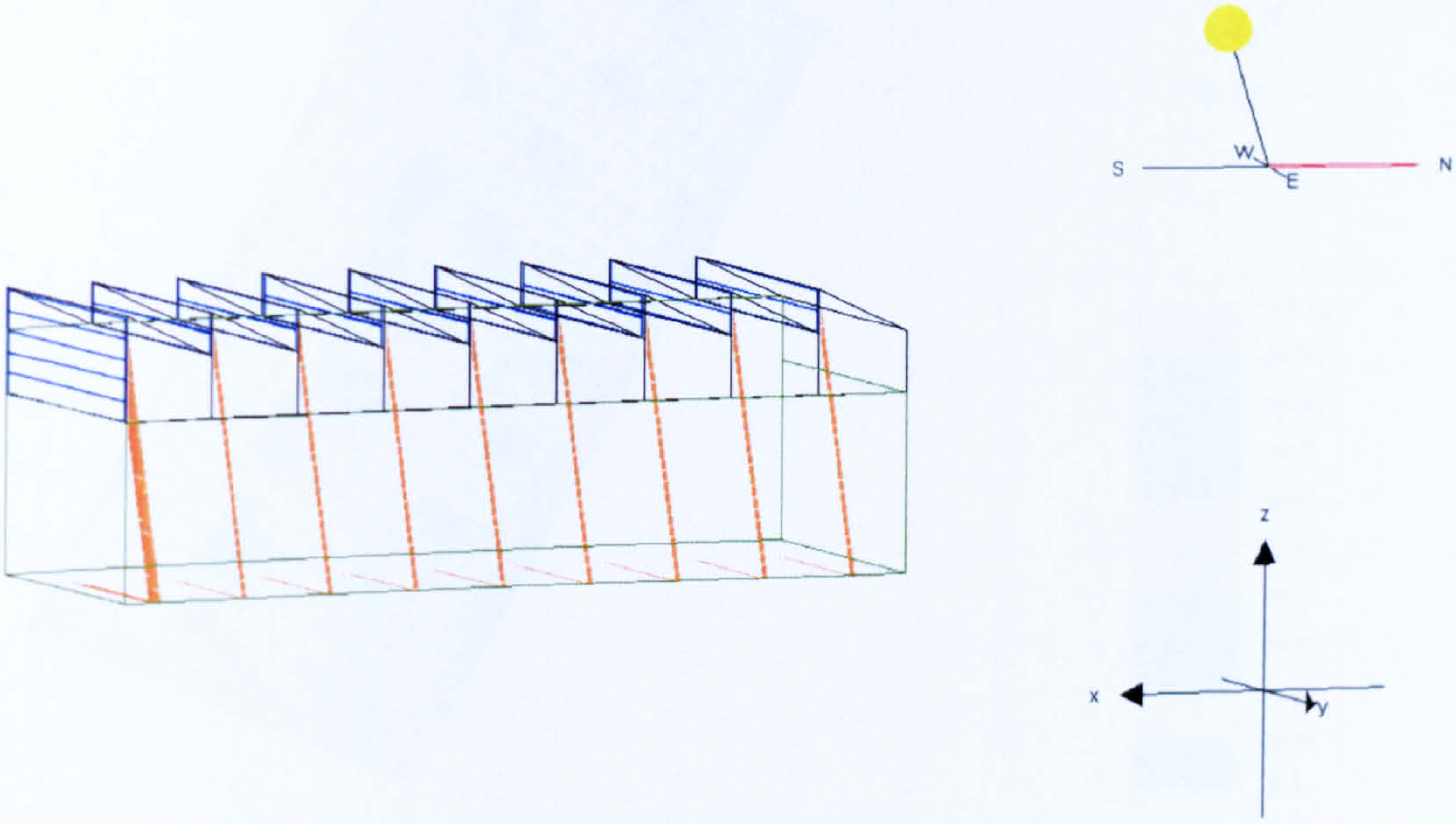


Figure 4. 37: The graph shows the sun patches inside the atrium space at 14:00 hours in June 22nd

Figure 4.38 shows the Percentage of People Dissatisfied in the atrium space in June at 14:00 hours and Figure 4.39 shows a graphical representation of the PPD for June 22nd. The first graph shows that generally, the percentage of dissatisfied people is between 10-19%. That percentage increases where patterns of direct solar radiation appear on the atrium floor. For the type of space and this research, the ability of the programme to analyse thermal comfort segment ally in a surface and the immediate environment around, it is considered a great advantage. That's because local discomfort is very common in largely glazed spaces such as the case study.

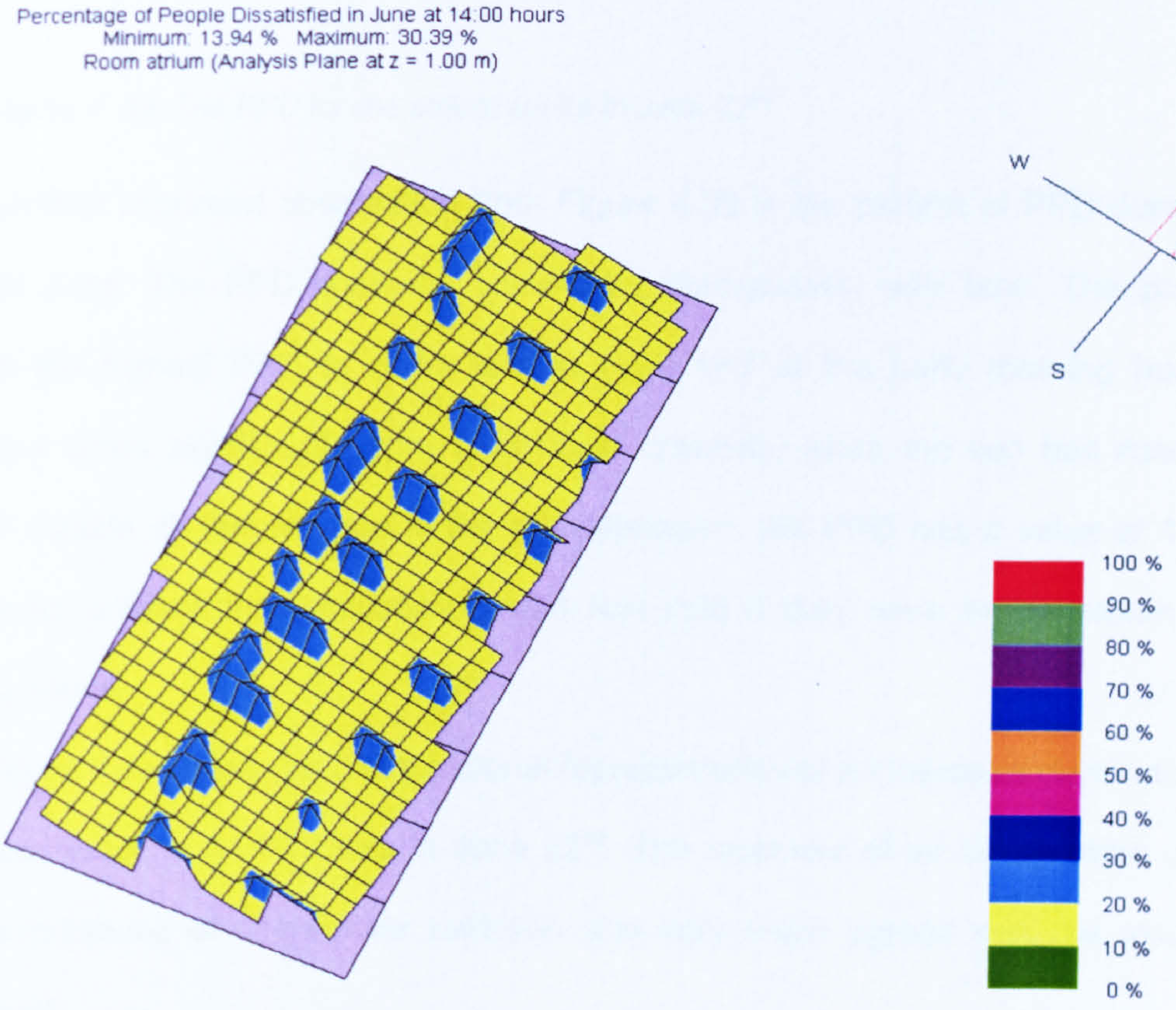


Figure 4. 38: Percentage of People Dissatisfied at 14:00 hours in June

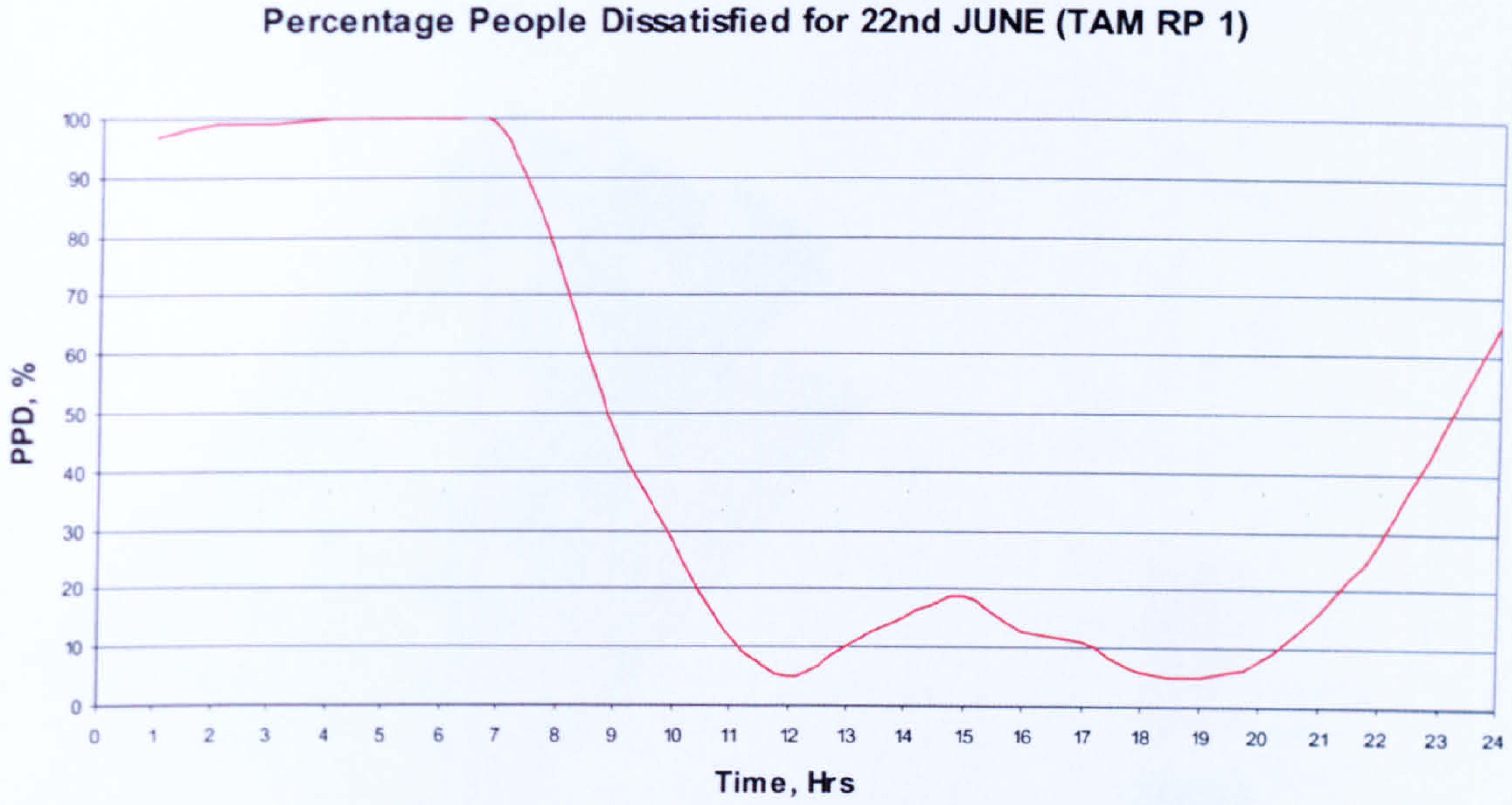


Figure 4. 39: The PPD for the atrium space in June 22nd

Another important observation from Figure 4.39 is the pattern of PPD during the 24 hours in June. The PPD changes, sometimes dramatically, with time. The programme predicts the highest PPD to occur late at night and at the early morning hours. This proportion drops significantly from 7:00 hours onwards, when the sun has risen. At the peak of outside air temperature in the mid afternoon, the PPD has a value of 19%. The programme predicts that occupants would feel cold if they were in the atrium in early morning hours.

Figure 4.40 shows the 3-dimensional representation of temperature distribution inside the atrium space at 14:00 hours in June 22nd. The local rise of air temperature coincides with the presence of direct solar radiation and very much agrees with the results from Figure 4.38.

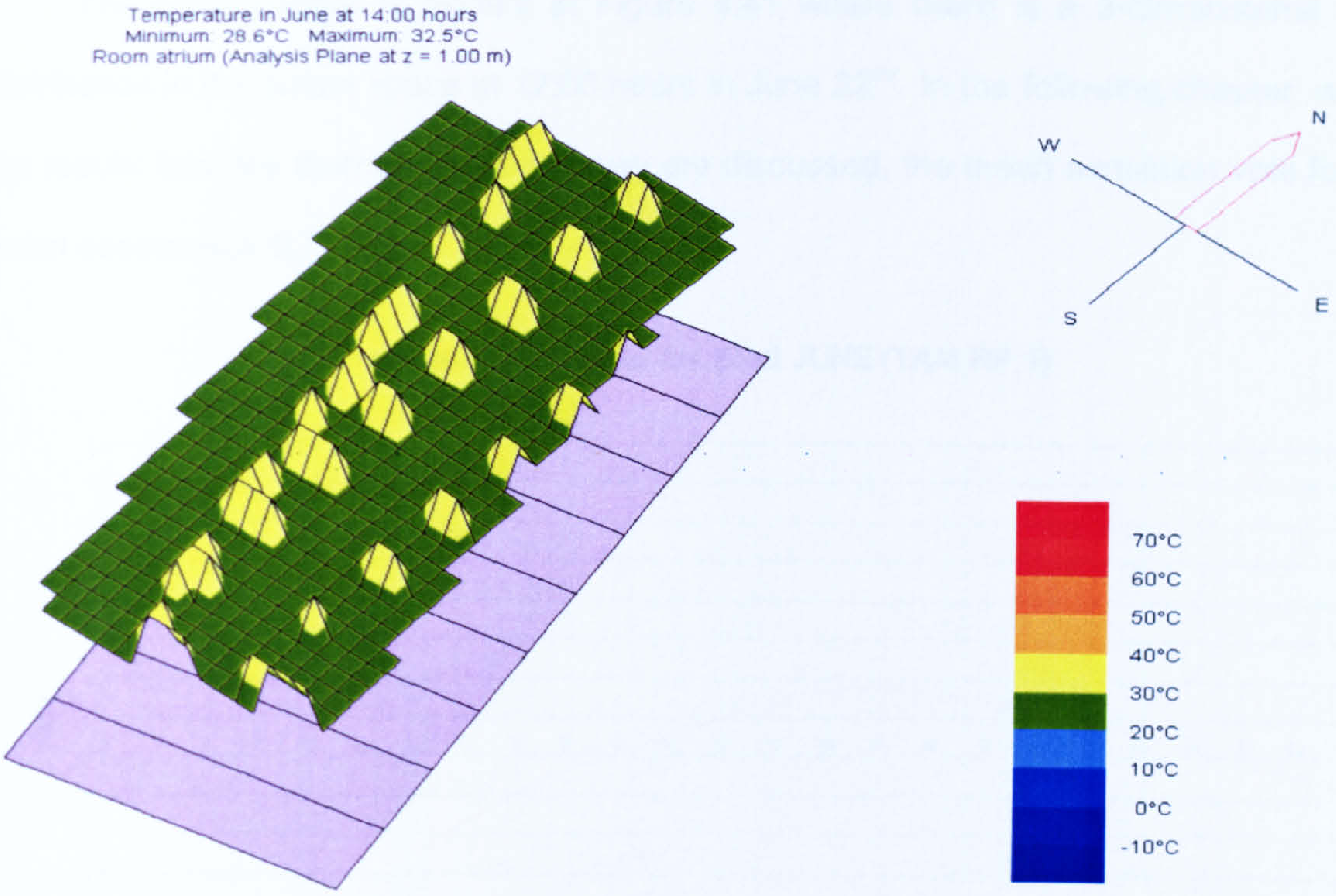


Figure 4.40: Representation of temperature distribution inside the atrium at 14:00 hours in June 22nd.

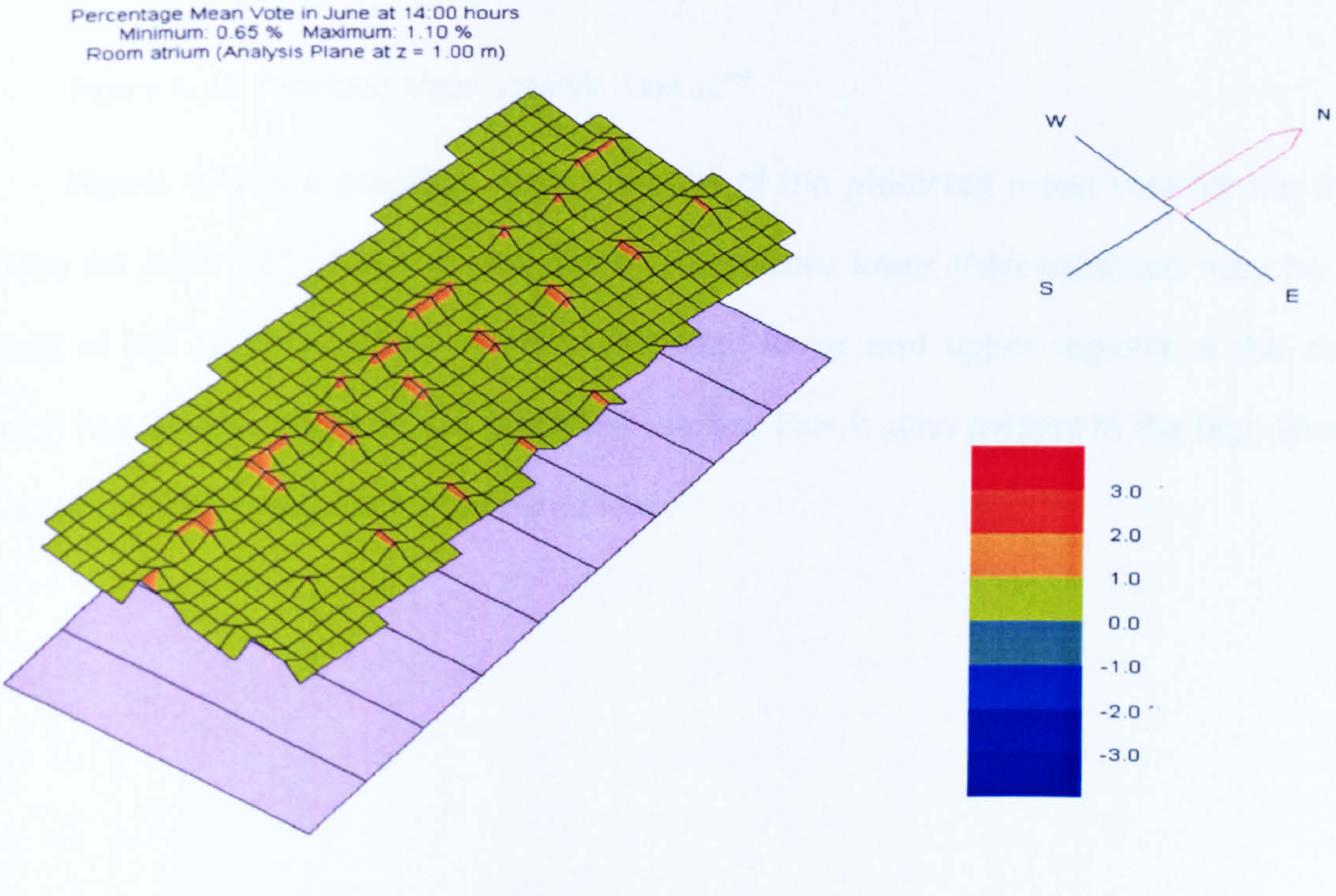
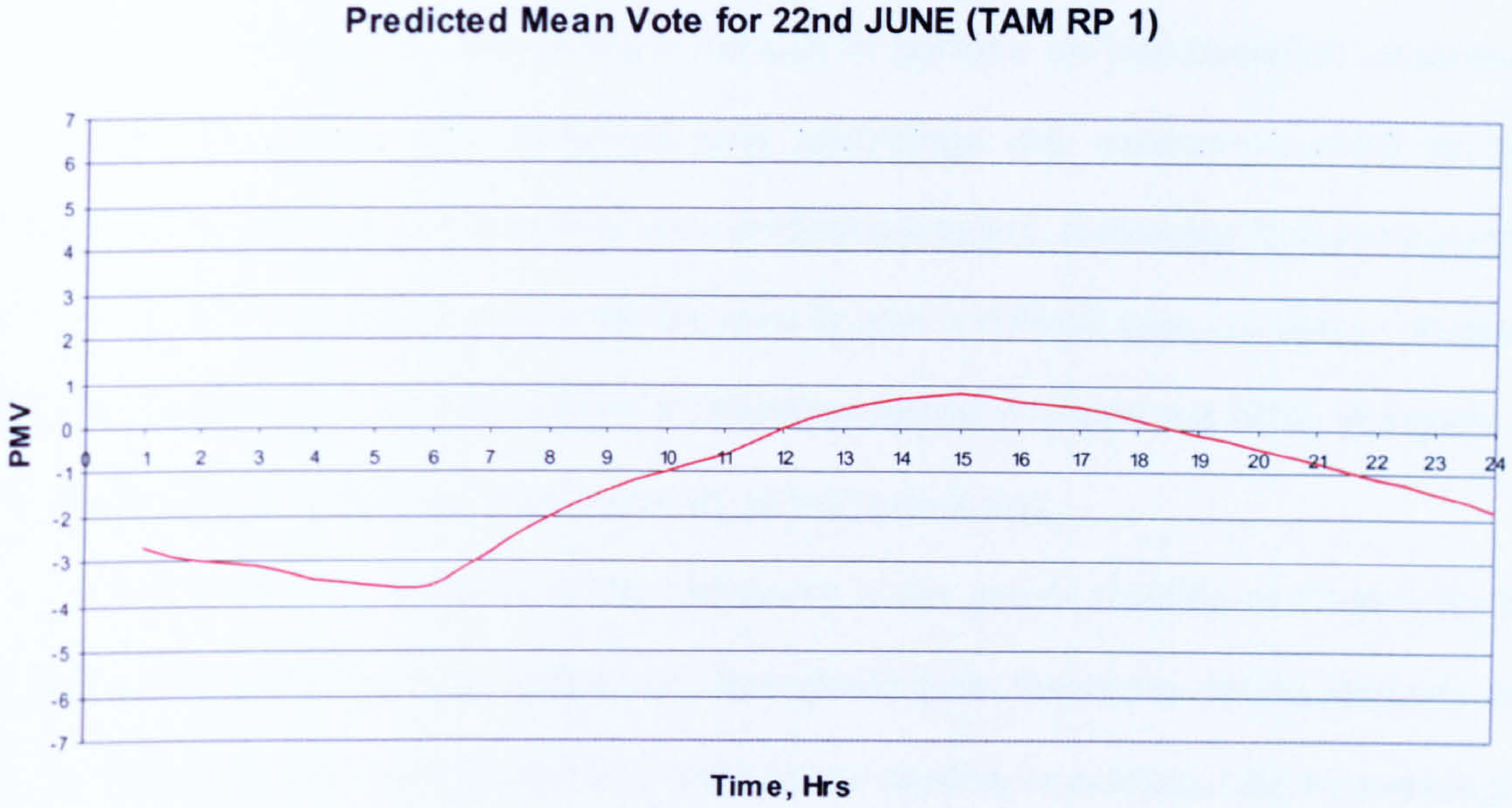


Figure 4. 41: 3-dimensional PMV distributions in the atrium space at 14:00 hours in June 22nd

The same pattern is evident in Figure 4.41 where there is a 3-dimensional PMV distribution in the atrium space at 12:00 hours in June 22nd. In the following chapter, where the results from the thermal comfort survey are discussed, the mean sensation vote for the warm season was 0.71.



Predicted Mean Vote for 22nd JUNE (TAM RP 1)

Figure 4. 42: Predicted Mean Vote for June 22nd

Figure 4.42 is a graphical representation of the predicted mean vote for the atrium space for June 22nd. The fact that the PMV appears lower than expected may be as a result of the air temperature inversion between lower and upper regions of the atrium, which has a wider effect on the predicted results. This is also evident in the high levels of relative humidity predicted for the same time.

4.5 Discussion

As it was discussed in a previous chapter, atrium buildings can provide ample daylighting but also result in complex interfacing of heating, cooling, and ventilating, the stratification of air, and problems with indoor air quality, and control of the environmental systems. Research of this interfacing is difficult to perform as simultaneous observations and continuous diurnal and seasonal data recordings are needed in order to better understand how the various systems and conditions interact. According to Kainlauri (1995) the analysis of observations and collected data is also a difficult task, as design conditions vary, the orientation of atriums differs, and environmental systems are often designed with inadequate understanding of the complexity of this interfacing.

In this section an analysis of the behaviour of an atrium building in Greece for both the cool and warm season is carried out. The results from the in-situ measurements show that the atrium space, even without any mechanical heating or cooling, had an overall good performance in relation to the ambient climate for both seasons.

The mean interior temperature in the cool season (12^0C) was quite satisfactory compared to the mean outside temperature (6^0C). For the warm season, the mean interior temperature was 25^0C, whereas the mean outside temperature was 24.25^0C.

During the warm season, the diurnal external temperature fluctuation was a lot higher than that inside the atrium. This is most likely to be due to the effect of the shape of the roof that excludes direct solar radiation from the atrium space at the time of peak outside temperatures. A 3-dimensional representation of the sun patches inside the atrium shows that the atrium is well shaded especially during the hottest time of the day. The atrium internal conditions affect occupants' sensation, which were analysed in the previous chapter and are in good agreement with the predicted results: during the time of peak summer temperature, less than 20% of the occupants are dissatisfied.

The heavyweight materials of the adjacent buildings were able to store heat during the day and reradiate it during night, when the temperatures go well below comfort levels during the cool season. For the warm season, the high thermal inertia of the walls of the adjacent buildings would seem to reduce the high fluctuations to within the comfort zones.

The measured data was also compared to the results predicted by the thermal and comfort analysis simulation programme. The predicted results showed very good agreement with those measured, as well as the results presented in the previous chapter.

For both seasons, the stratified temperature results show that stratification increases directly with outside air temperature, although the difference is larger during the cool season. The comparison of measured and predicted data has high correlation, and the internal conditions in the atrium are visualized by the 3-dimensional representation of the sun patches, the PPD, the temperature distribution and the PMV.

The overall conclusion is that less stringent thermal comfort requirements for atrium spaces should be considered. Especially during summer, where the ambient temperatures are very high and can create highly uncomfortable conditions, the atrium temperatures were within or very close to the comfort limits. It was therefore evident that there are weather conditions when the atrium's interior air temperature will be comfortable without the need for heating or cooling These conditions can and should be identified, and incorporated later in the process of the parametric study.

4.6 Conclusions

This chapter has focused on the analysis of the thermal performance of an atrium building in Greece, for both winter and summer seasons, and the comparison of the measurements with those predicted by the simulation programme.

The purpose of this was to check the accuracy of prediction using the simulation programme. This would establish whether the programme could be used to predict internal thermal conditions in an atrium building, in the climatic context of Greece with certain reliability and thus be used in subsequent analyses.

The experience gained from being able to compare the measured results with the simulation results was invaluable. It provided not only validation of the computer programme but also practical experience on the thermodynamic behaviour of the space.

The temperatures predicted with the dynamic simulation programme correlated very well with the measured results. Additionally, the programme was used to perform thermal comfort analysis and predict the PMV and PPD on selected days. The results were in very good agreement with those analysed in the previous chapter for both seasons.

Having discussed the background issues i.e. climate, atrium buildings, having analysed the results from the thermal performance of an atrium building in Greece, and having validated the dynamic simulation programme against those results, the next chapter concentrates on the analysis of the thermal comfort survey performed in the case study atrium building in Greece and attempts to evaluate the thermal conditions that occur in atrium buildings set in a Mediterranean climate as perceived by the users.

Because the material presented in this chapter is specific to a certain project, there is some caution in generalizing about the effect of atrium thermal performance on occupants' comfort. However, it is important to note that specific cases present examples of the keys to comfortable, climatic responsive atrium space in today's urban environment. The results from the thermal comfort survey and the monitoring of the atrium building in Greece, as well as the knowledge of thermal processes and design factors for atrium buildings, will be used as a data input for the parametric study in a following chapter that will lead to design guidelines.

CHAPTER 5

THERMAL COMFORT - THERMAL COMFORT SURVEY IN AN ATRIUM BUILDING IN GREECE

5.1. Introduction

This chapter attempts to evaluate the thermal conditions that occur in atrium buildings set in a Mediterranean climate as perceived by the users. In the previous chapters there has been an introduction to the building type (atrium/glazed space), the climatic context (Mediterranean), and the thermal processes that occur inside these types of buildings. In the last chapter, the results of monitoring the performance of an atrium building in the specific climatic context were discussed. If the hypothesis stated in the first chapter is true, and the building has a poor performance during wintertime and becomes overheated during summer months then that should be reflected in the occupant's response through a level of dissatisfaction.

It should be also stated however, that the current thermal comfort survey had some limitations. Due to luck of equipment, only measurements of air temperature and relative humidity were taken. A difficulty in setting them up and the matter of their security was also encountered. The site chosen is a public education building, leading to time constraints as the factors needed to be measured in full would result in a 6 month survey where the researcher would have to stay in the site. The most important reason however, is the fact that this survey was intended simply to give results that would allow to verify the hypothesis; to give an insight of how the building performs in context with the ambient climate, and more importantly how do the occupants feel. That was a crucial part of the research as there are no previous recordings of occupants' satisfaction/dissatisfaction from the specific context. The survey was also an important insight into which major factors can be taken into account by a designer and lead us to the parametric study and the design guidelines.

The major part of this chapter concentrates on the thermal comfort survey in Greece, its design and limitations, followed by an analysis of the results.

5.2.Thermal Comfort Survey

5.2.1 Introduction

This part of the chapter describes the methodology adopted for the field study, together with the equipment employed for the environmental monitoring, the design of the questionnaire and the analysis of the survey results.

Depending on the season, the design condition and the designer's primary concern will change. Regions between the latitudes of approximately 30 and 45^0 N are considered having cool winters and hot summers. Greece is approximately between the latitudes of 34^0 and 42^0 N. During the heating season, maintaining air temperature and preventing cold drafts (air movement) are usually the most important considerations. However, in summer, cooling becomes most important, followed closely by humidity control. At a relative humidity greater than about 60%, people lose their ability to stay comfortable through sweating. When the humidity is low people are comfortable at higher temperatures, and often claim that the air feels fresher. However, the ultimate in unpredictable conditions is the weather. The ambient temperature, the moisture in the outside air, the direction and velocity of the wind, and the intensity, quality and direction of the sun are all beyond the control or accurate prediction of humans. Additionally, the sequence of the above ambient conditions is also important. All of these factors contribute to the thermal load on the building and the comfort of the occupants. Designers can only react to these conditions, and try to design systems to maintain comfort through all of them at the lowest possible cost and the lowest possible impact on the environment.

In order to study climate sensitivity or thermal performance of buildings, the knowledge of thermal comfort standards is important. Therefore, in this thesis it is considered necessary to investigate thermal comfort, before embarking on the study of thermal performance of atrium buildings in a Mediterranean climate.

The thermal comfort standards are used as benchmarks against which the thermal conditions of a building are estimated to establish its thermal performance. Thus, it is important that thermal comfort is studied in this research.

Many researchers in the field have pointed out that comfort is one of the most important objectives of building design, as the history of building (shelter) is one that has taken the fabric as a modifier between the exterior and interior climates or to shelter from extreme weather conditions. Thermal comfort in building design is important because of people's desire to feel thermally comfortable and also their intellectual, manual and perceptual performance is generally highest when in thermal comfort (Fanger 1972). Furthermore, in some recent surveys in office buildings in UK Bordass and Leaman (1997) have shown that there is a relationship between perceived thermal comfort and perceived productivity which confirmed Fanger's argument discussed above.

Although Fanger comments that, "wherever possible, the temperature be adjustable, so that the person preferring 17°C or 27°C can adjust his/her individual area, assuming they have the means to do so" (Bunn 1993), currently thermal comfort standards are taken as being the same worldwide regardless of climate. These are stipulated in the international standards ISO 7730 and are based on studies done in the climate chamber in temperate climates by Fanger (1972).

However, for some time it has been observed that there has been an apparent discrepancy between comfort predictions using models derived from laboratory experiments and subjective assessments of comfort found in field studies

Comparing results of field studies has shown a rather close relation between the preferred indoor temperature and the mean outdoor temperature for the location and the season of the year (Humphreys 1978). For occupants of buildings where no energy is being supplied for heating or cooling plant, there is a linear relationship between the preferred indoor temperature and the mean outdoor temperature, such that the preferred indoor temperature increases by approximately 0.5^0C for every 1^0C rise in the outdoor air temperature (CIBSE 1986).

In a compilation of results from 47 filed studies, predominantly in warm and hot climates, Humphreys (1978) found that the preferred comfort temperature T_m in buildings was a function of the average monthly outdoor temperature:

$$\mathbf{T_m = 0.55T_o + 14.1} \qquad (5.1)$$

Where T_o is the mean monthly temperature

The results are shown in figure 5.1. The indoor temperature is changing at only half the rate of the outdoor temperature. At temperatures in excess of about 31°C (at which point $T_m = T_o$) the indoor temperature is below outdoor temperature, at temperatures below this figure indoor temperature exceeds outdoor temperature by an increasing amount. Even in buildings with no heating or cooling plant, the occupants' efforts to achieve a comfortable environment reduces changes in indoor temperatures below those in outdoors temperature. They achieve cooling in hot conditions and warming in cool conditions.

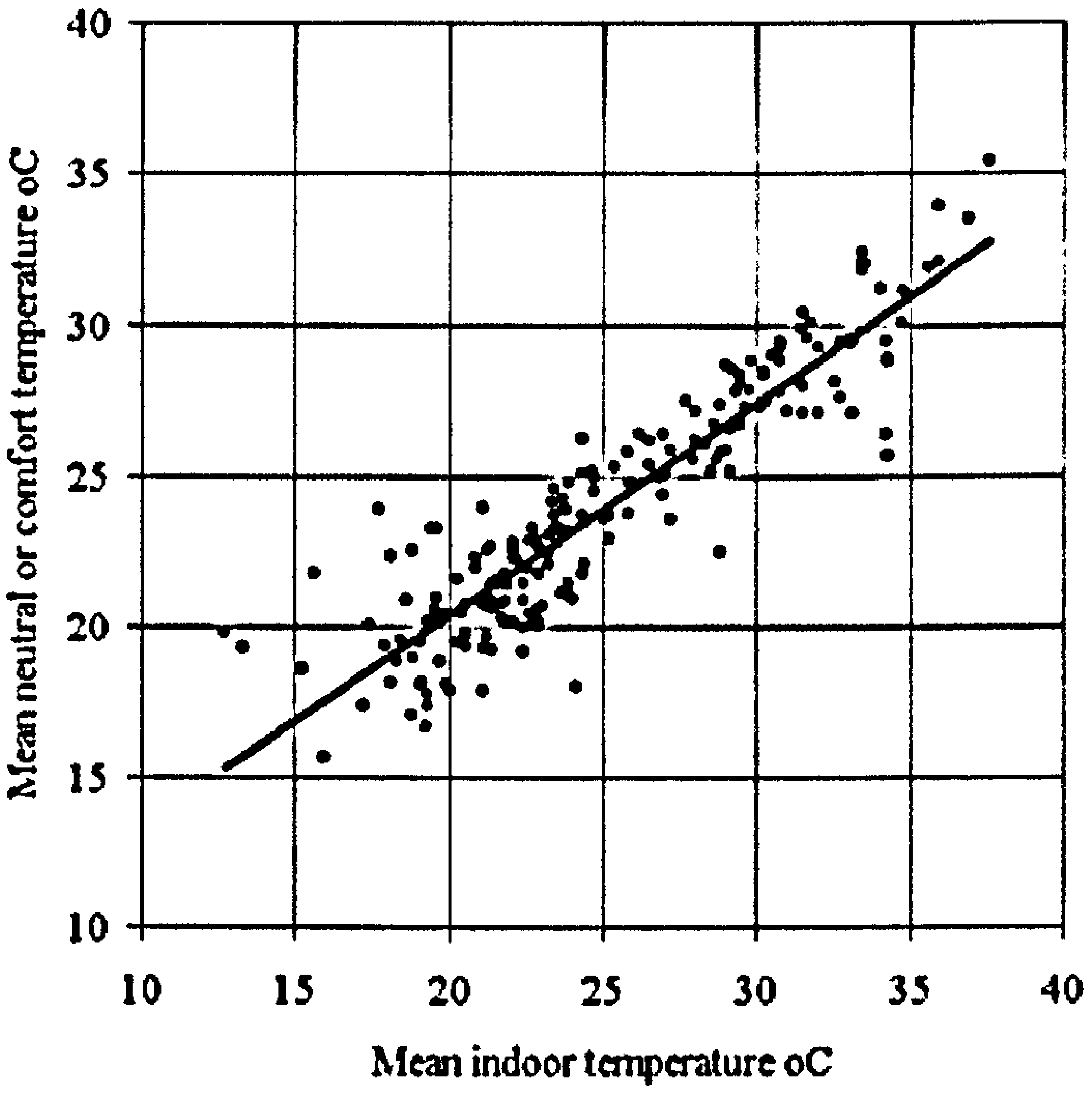


Figure 5. 1: The graph shows how the mean comfort temperature varies with the mean indoor temperature. Each point in the graph is the mean value for a whole survey.

Recent hot-dry field experiments include those by Baker and Standeven (1994) in residential buildings during the summer in Athens, Greece. Their results indicated the importance of adaptive opportunity in order for building occupants to accept temperatures warmer than 24°C and that typically 70% of subjects were satisfied at an operative temperature of 27.8°C.

5.2.2 Atrium Comfort Survey: Methodology

This paragraph describes the methodology adopted for the field studies, together with the equipment employed for the environmental monitoring, the design of the questionnaire and other aspects of the work.

According to Humphreys (1976) the two main purposes of field studies are to find a way of describing the thermal environment, which correlates well with human response, thus enabling reliable predictions to be made, and to define the range of conditions found to be pleasant or tolerable by the population concerned.

The site chosen was used as the medium for examining comfort conditions in glazed spaces in a Mediterranean climate. The glazed space has a typical courtyard arrangement. It is within a University building, on the outskirts of the city of Ioannina, Greece. The primary objective was to collect and compare objective and subjective data, in order to evaluate the thermal comfort conditions people were experiencing. That was achieved by recording environmental parameters and comparing the results with the subjective responses from the interviews.

In this field study there were three methods used for acquiring information: survey, observations and field measurements. Over recent years, two basic designs of surveys have been used; the "longitudinal" and the "transverse". In the former type comparatively few respondents provide repeated assessments of sensation over a period of weeks or months. From this type of survey it is possible to investigate the consistency of individual response and to observe the progress of adjustment to changing conditions. Because of the small number of respondents employed such a study may not provide data that is representative of the wider population. In the "transverse" survey a large number of respondents are asked to make only one assessment. This type of study indicates the extent of variation among individuals' responses and gives good estimates for the population as a whole.

A transverse type of questionnaire was designed for this study with a combination of "open" and "closed" questions. The questionnaire was administrated in the Hellenic language. Closed questions were employed for the first part of the interview, where the respondent's evaluation of thermal environment was sought, whereas open questions were employed for the following part examining use of the space.

The point scale used was from (-3) for cold to (+ 3) for hot. For the preference, the wind, the humidity and the visual comfort there was used a 3 point-scale. The questionnaire also aimed to examine the subject's thermal balance (and therefore sensation vote) and test whether thermal comfort conditions affected the extra time they spent in the space. The subjects were asked to give a rating in a 3 point scale and to give an answer as to what would they do to feel more comfortable.

The subjects were also asked to identify the place they had been immediately before coming to the atrium space and how much time they had spent already inside the atrium space. That was vital information to take under consideration as people coming from outside the building were experiencing more harsh weather conditions (cooler in winter and warmer in summer). Also it was very important for the survey that the subject had spent more than 10 minutes inside the atrium and would have adequate time to acclimatize. Another important issue was to investigate how familiar they were with the space (regular /frequent user or occasional visitor).

The questionnaire also recorded the clothing of the subject, the kind of activity he/she was involved before coming to the atrium, the frequency and the time of the day they spent in the atrium. Some personal questions were handled in a careful way so that the subject wouldn't feel any threat.

In a transitional space like the glazed courtyard in Ioannina, when approaching strangers, persuading them to fill a questionnaire was sometimes difficult. The researcher sometimes had to stress that the questionnaire was of a short duration, 3-5 min, since many people were reluctant because of the duration. Convincing people to participate in the interviews was not easy and refusal was as common as acceptance, but did not seem to have any particular bias.

The field studies took place during winter 1999-2000 and summer 2000 in the atrium building of the Philosophic School at the University of Ioannina, Greece. The local climate has been analysed in chapter 3. The subjects interviewed were from the same climatic background (i.e. the Mediterranean). A copy of the questionnaire is included in APPENDIX B.

The interview periods started at 9 a.m. and finished as late as 11p.m. covering a duration of more than a 12 hour period, almost all the time that the space was inhabited by occupants or visitors. This varied between winter and summer months (during the winter months the duration of the survey was less since the space was left unoccupied after a certain time).

Altogether there were 350 sets of responses for both seasons (winter and summer). The choice of equipment for the climatic measurements was based on certain criteria:

- accuracy
- easy to use and set up
- size-portability
- ability to measure as much of the variables required
- ability to store a large amount of data

The data loggers employed for the measurements were the HOBO H8 series (full description of the equipment is given in APPENDIX A).

5.2.3 Environmental Monitoring

Environmental monitoring was crucial in order to determine the climatic conditions of the space under consideration. Air temperature, relative humidity and light intensity data loggers were employed to measure ambient conditions within the space.

For each field study, a data logger was set to record every 10 min for the period of the interviews (10 days for each field survey). Another data logger was set to record hourly data for a continuous period of 3 months each in winter and summer months, so as to indicate the variety of thermal conditions encountered in the same area over time. For security reasons, the data loggers recording data over a 3-month period had to be installed in places where it would not be easy to reach them. To ensure that the users of the space would not tamper them with and therefore secure, staff from the Technical Services of the University of Ioannina were employed in order to tape them in one of the beams of the metallic structure that supports the glazed roof. A thick piece of cotton was placed between the data logger and the metallic element to provide a degree of insulation.

To be able to compare subjective with objective data of thermal comfort, it was necessary to monitor the climatic conditions the interviewee was exposed to, by monitoring variables involving air temperature and relative humidity.

5.2.3.1 The Measured Environmental Variables

From the four environmental variables affecting thermal comfort sensation (air temperature, relative humidity, mean radiant temperature and air movement) it was decided to use the air temperature and relative humidity variables in order to analyse the results and determine the thermal comfort zone.

The reasons for doing so are based on the fact that the air temperature and the relative humidity are the two climatic variables most easily understood by the occupants of an enclosed space and by designers less familiar with thermal comfort and building thermal performance indicators. Additionally, these were the two environmental variables measured from the monitoring equipment in the atrium building in Greece. Therefore, in this study, air temperature and relative humidity are used in order to describe the thermal performance of the atrium building and therefore the thermal comfort zone is based on these two factors. Nevertheless, the mean radiant temperature and air velocity are also discussed where they are considered important factors in describing the thermal performance of the monitored building.

Logging of the variables was, averaged and recorded every 10 min. Since the interviews lasted around 5-10 min, the mean value recorded was representative of the actual conditions, which is also the recommendation of ISO 7726, where a mean value of a 3 min period is considered desirable. The data logger timer and researcher's watch were carefully synchronized, so that the actual interview period could be directly related to the recorded thermal parameters, to eventually calculate an average value for each parameter to include in the PMV model as representative of the subject's thermal environment.

5.3 Analysis of the results

The process used to investigate thermal comfort was the field survey (including a questionnaire, observations and environmental monitoring). The second stage now described is the statistical analysis of the data from the survey.

There is a wide variation among thermal comfort studies in the completeness with which the thermal environment has been measured. The data recorded varies from simple temperature measurements to complete environmental records including those of surface temperatures of all walls, ceilings, etc. (Humphreys 1976). In the Ioannina field study, two sets of data of air temperature and relative humidity were recorded: the first reflected the environment that the subjects and the researcher were experiencing and the second the environment at height of 4 m. The data logger attached to the beam of the structure that supports the roof recorded the latter and it was placed approximately 2 m from the nearest wall.

The relative humidity data were changed to water vapour pressure using the following equation:

$Pa = RH \times \exp[18.956 - 4030.18/(Ta = 235)]$ (millibars) (McIntyre 1980) (5.2)

Air velocity was not measured but since the site of the field survey was a shielded environment, the airflow conditions can be estimated by the subject's answers from the relative part of the questionnaire.

According to Humphreys (1976) a common way of analysing field study observations is to find the proportions of the assessments, which are in the several response categories, over the range of environments encountered during the study.

In this part of the chapter, the results of the thermal comfort field study are presented highlighting the comfort/preference voting patterns and the comfort temperature. Humphreys (1994), and Nicol and Roaf (1996) demonstrated that people use various control methods to adapt to the changes in the environment to improve their comfort. The adaptive behaviour of the subject has also been investigated and the comfort zones for both the cool and the warm season are discussed.

5.3.1 Statistical Analysis

The results from the recordings and the questionnaires were imported in a statistical analysis package. SPSS 10.0 (Statistical Package for the Social Sciences) is a data management and analysis product. It can perform a variety of data analysis and presentation functions, including statistical analyses and graphical presentation of data (Kinnear, 2000).

It consists of two parts: the Data File processor and the Output Files. Importing or inputting data in the data processor can create data files. The output files have graphical or tabular outputs and it enables to see the data in the forms of scatter diagrams, histograms, bar charts or regression charts.

5.3.2 Summary results

5.3.2.1 Subject Information

The total samples of responses were 300, 100 during the cool season and 200 during the warm season. There were a smaller number of questionnaires completed during the cool season due to the time of the field survey approaching the Christmas vacation. The total number of the people occupying the Philosophic School of Ioannina is around 1000 (200 teaching, secretarial and other staff, 700 underground students and around 100 Post Graduate Students). There is also a number of maintenance staff (technicians, gardeners, porters, cleaners, canteen staff). Table 5.1 summarises the data for gender, weight, height, body shape and occupation of the subjects.

GENDER	Frequency	Percentage %
F	176	58.7
M	124	41.3
TOTAL	300	100%

	WEIGHT	**HEIGHT**	**BODYSHAPE**
Mean	67.7	1.71	0.63
Min	45	1.60	0.03
Max	100	1.86	2.19

OCCUPATION	Frequency	Percentage%
Student	184	61.3
Teaching Staff	43	14.4
Other Staff	54	18
Visitor	19	6.3
Total	300	100

Table 5. 1: Statistical summary of personal information for all the questionnaires

From all subjects there 176 were female and 124 male. 184 subjects were students, (undergraduate and post-graduate), 43 were teaching staff, 54 subjects had an occupation amongst the other staff that regularly visits the building and 19 were visitors. The age of the subjects ranged from 18 to 65 years.

5.3.2.2 Distribution of physical and subjective data

Before starting analysing the data, it was plotted in various ways:

- Physical variables and comfort against time of day
- Frequency plots of comfort vote and the physical variables
- Comfort vote against physical variables
-

Plots against time of day: Plotting the physical variables against time of day gives a lot of information about the conditions the subjects have experienced and the comfort votes how they reacted to them.

Figures 5.2 and 5.3 show a daily variation in the temperature values, which is expected, as the atrium space is not environmentally controlled. There can also be seen the different range of temperatures the subjects were exposed to during the interview period. The widest range of temperatures for the cool season was from 11°C to 16.6°C at midday (12:00p.m.). For the warm season the temperatures at the time of interview varied from 19°C to 29.2°C at a range of interview time form 9:00 a.m. till after 11:00 p.m.

In interactive graphs 5.4 and 5.5 the sensation votes are plotted against the time of the interview for the cool and the warm season respectively. In the cool season the sensation votes are very close to comfort vote (0) until the first afternoon hours. In the warm season the sensation votes are more evenly distributed close to being slightly warm except for the early morning and evening hours. It would be interesting to see in further analysis whether these changes had any effect on people's movements and activities or their time of abidance of the atrium space.

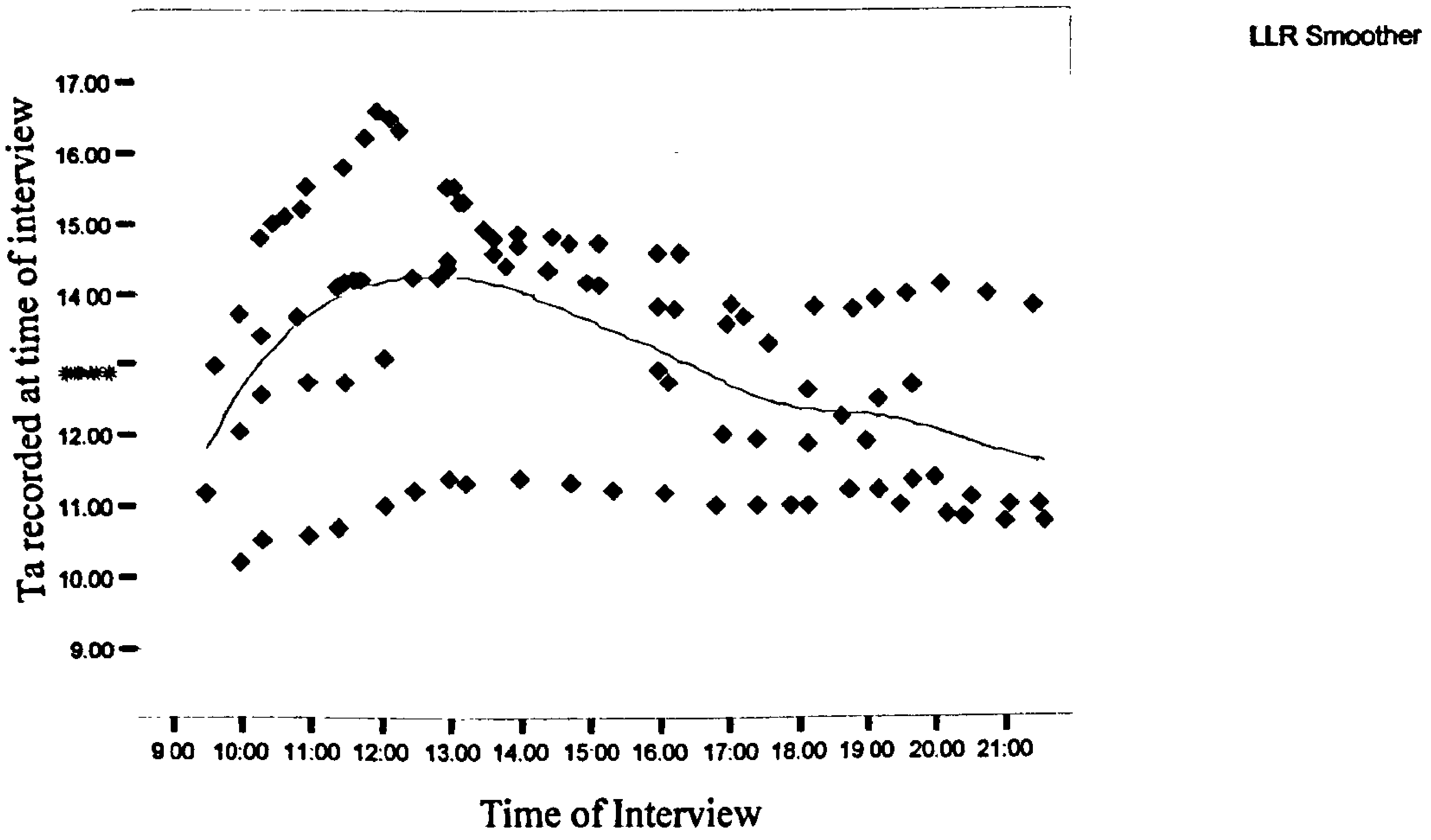


Figure 5. 2: Range of temperatures recorded against time of interview in the cool season

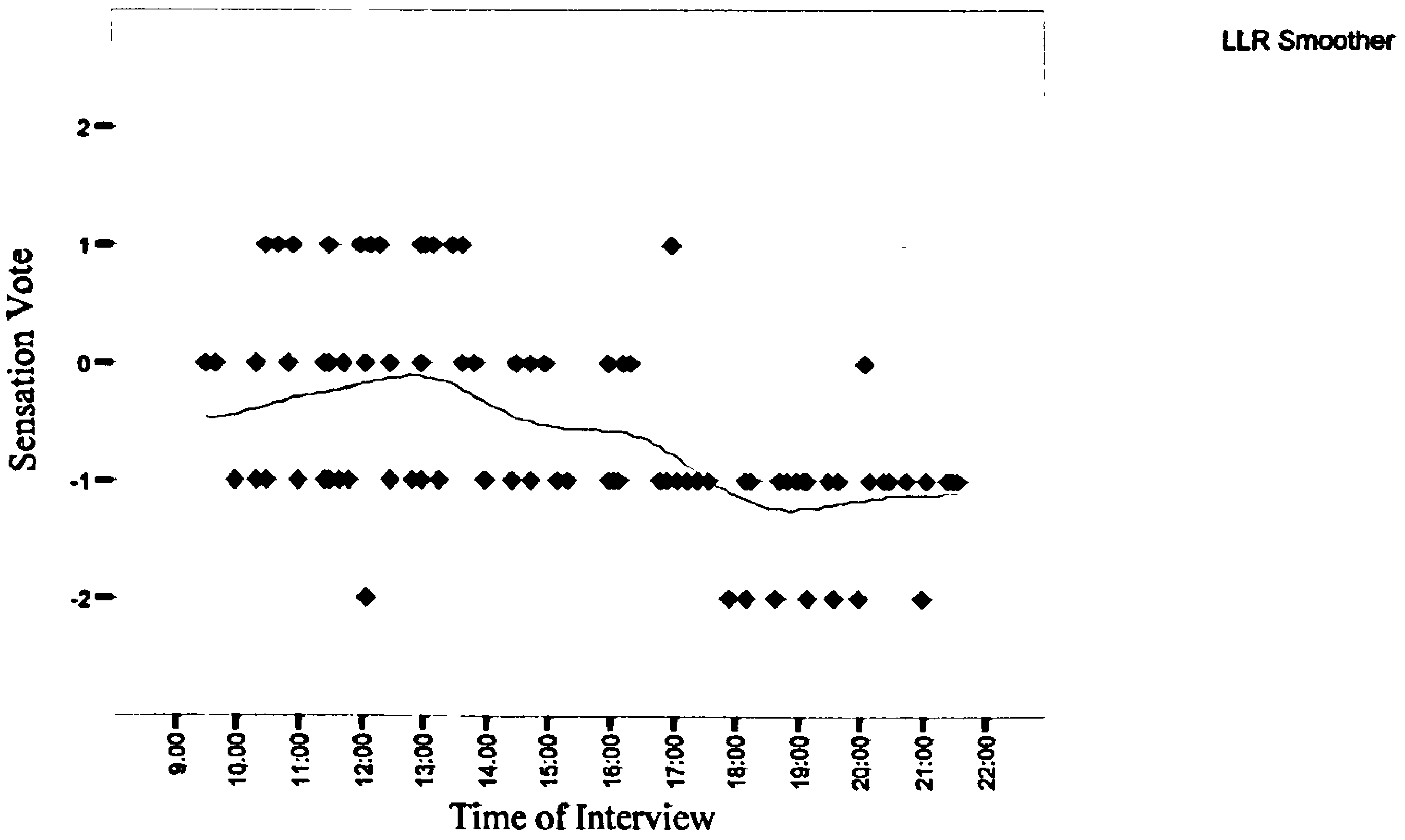


Figure 5. 3: Sensation vote against time of interview for the cool season

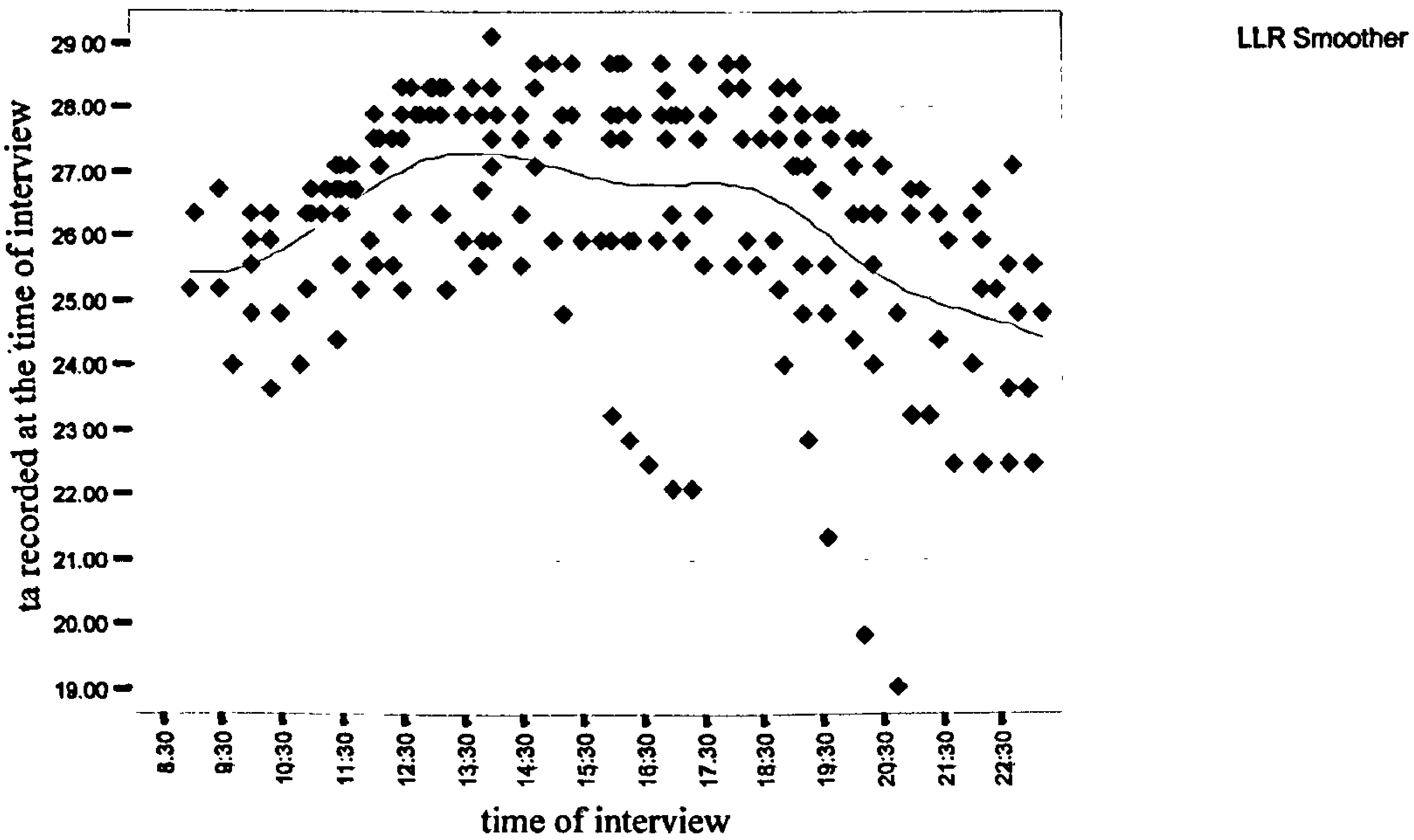


Figure 5. 4: Range of temperatures recorded e against time of interview in the warm season

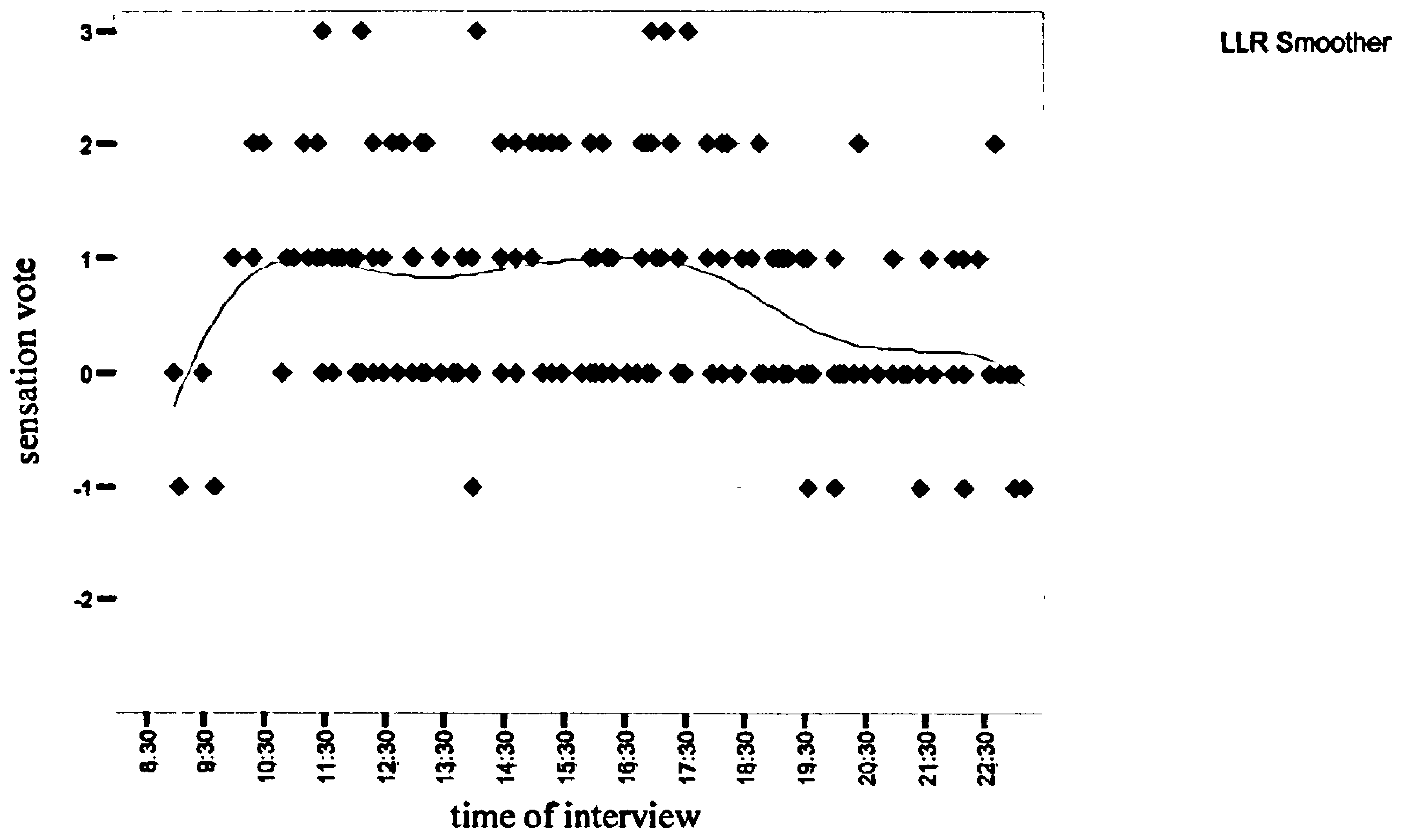


Figure 5. 5: Sensation votes against time of interview in the warm season

Frequencies: From the frequency plots there can be yield useful information about the range of conditions the subjects were experiencing, and therefore range of applicability of the results. It is also useful in getting a feel for the distribution of the overall results. If the values are asymmetrical, then it should be reflected also in the statistical analysis of the data.

Figure 5.6 shows the frequency distribution of the temperature the subjects were exposed to in the cool season. The temperature ranged from 10.21^{0}C to 16.6^{0}C. The distribution shows that there is a concentration between 11-12 ^{0}C and between 15–16.6^{0}C. The mean temperature was 13.23^{0}C. It is also important to note that the highest temperatures occur at 11:00 hours and at 14:00 hours. Presumably, the same pattern should be evident in the results of the occupants' sensation and it will be investigated further in comparison with the thermal simulation results in the next chapter.

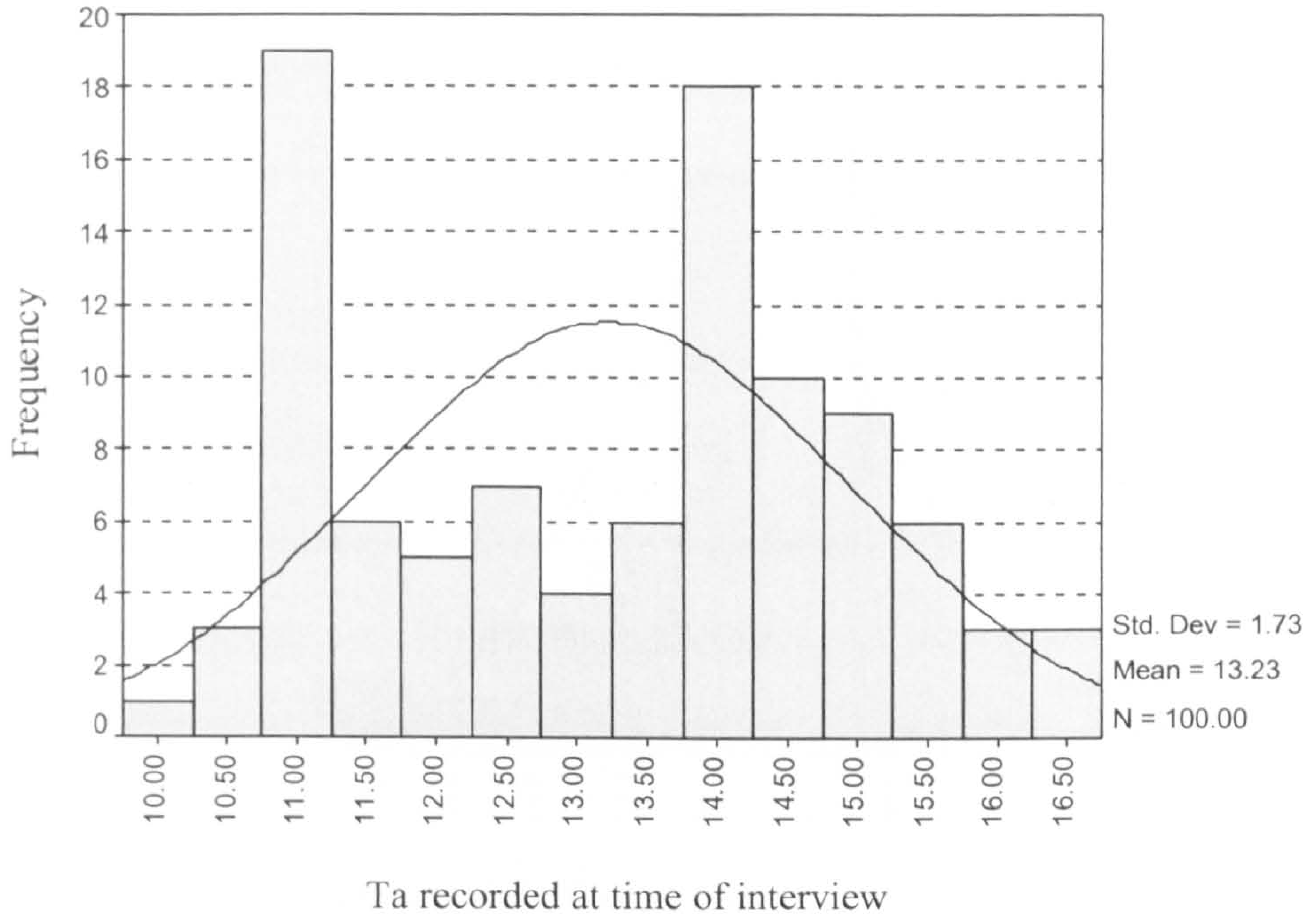


Figure 5. 6: Frequency distribution of temperature at time of interview in the cool season

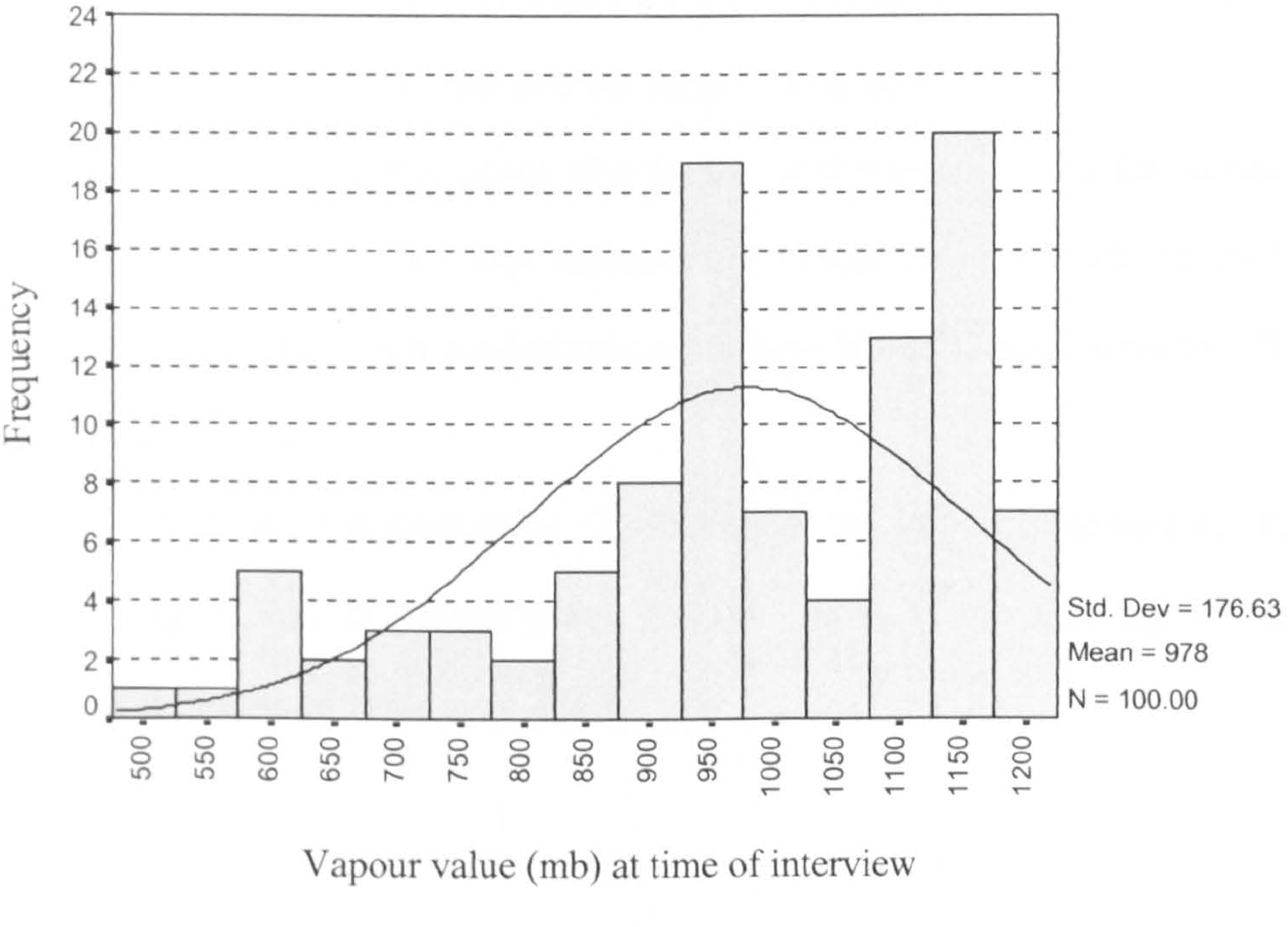


Figure 5. 7: Frequency distribution of vapour pressure at time of interview in the cool season

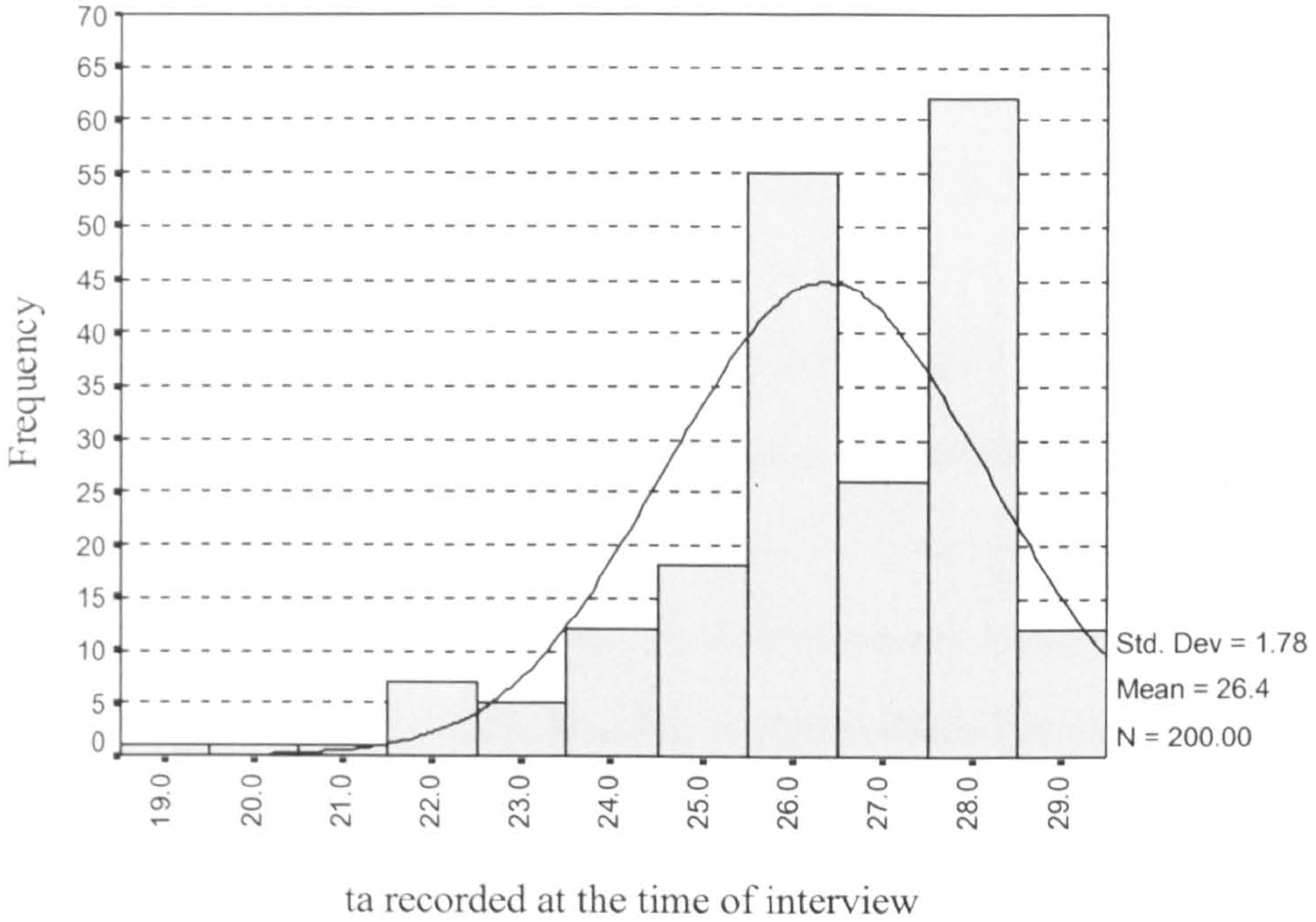


Figure 5. 8: Frequency distribution of temperature at time of interview in warm season.

Figure 5.7 shows the frequency distribution of the vapour pressure. This set of data derived from the Relative Humidity measurements using equation 6.1. The range of vapour pressure was 497 – 1212 mb and the mean value was 977,8mb.

Figure 5.8 shows the frequency distribution of the temperature the subjects were exposed to in the warm season. The temperature ranged from 19.04^{0}C to 29.1^{0}C. The distribution shows that there is a concentration between 26-28^{0}C and between. The mean temperature was 26.37^{0}C.

Figure 5.9 shows the frequency distribution of the vapour pressure for the warm season. The range of vapour pressure was 766.06 – 1744.41 mb a lot higher than in the cool season, and the mean value was 1389.8 mb.

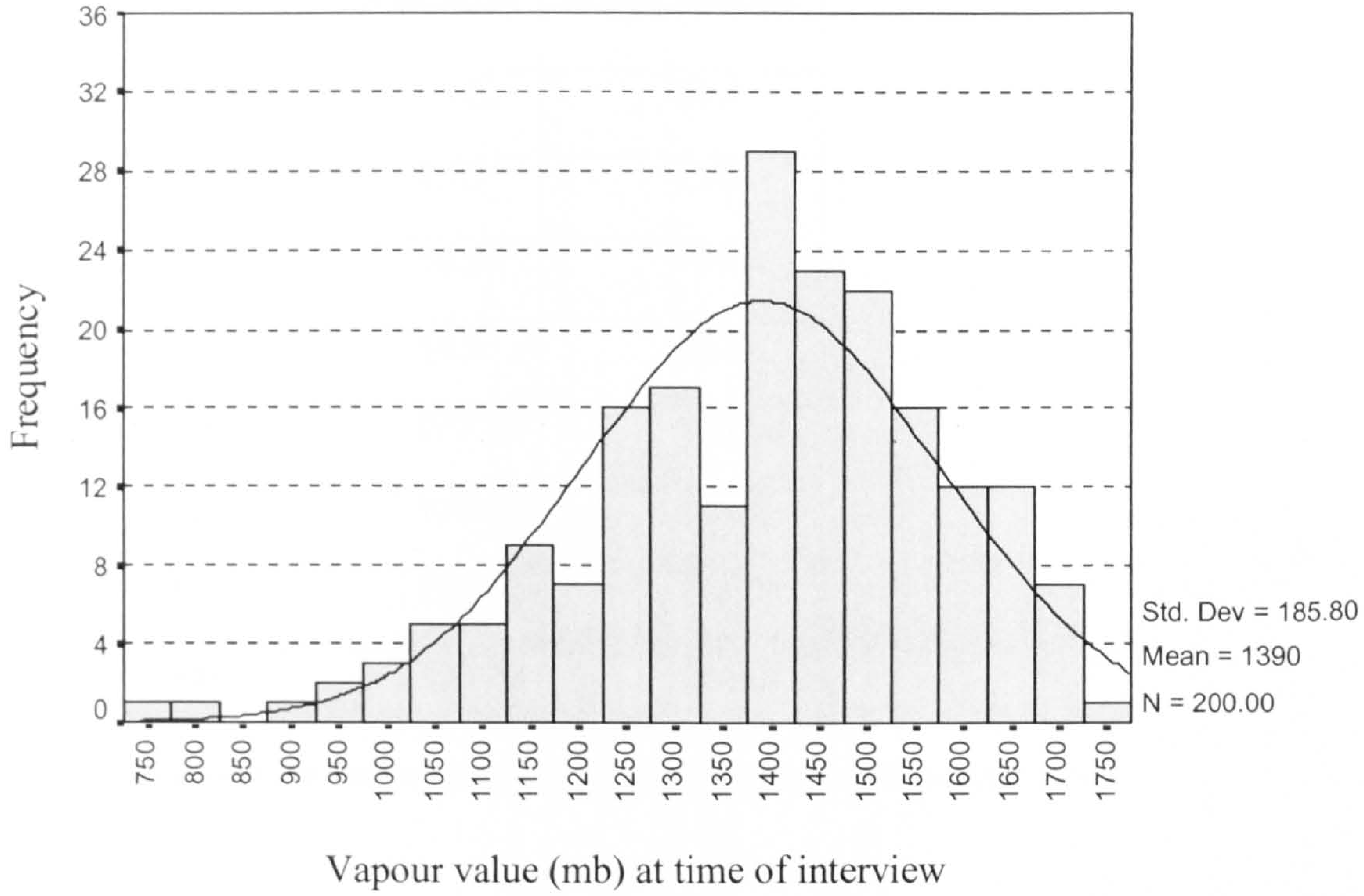


Figure 5. 9: Frequency distribution of vapour pressure at time of interview in warm season

Although air velocity was not measured during the field surveys, there can be an estimation of the value of airflow according to the subjective responses of the questionnaires in comparison with the external weather data and the observations made by the researcher. During the cool season, the space was shielded from external weather conditions. During the warm season operable windows in the glazed roof were open for ventilation.

In this research temperature is the main comfort index against which most of the obtained data will be plot. Clothing value as well as metabolic rate can be calculated from the information obtained from the questionnaires. However, the main aim of this survey was simply to give results that would allow verifying the hypothesis of how the building performs in context with the ambient climate and how do the occupants feel.

		Cool Season	Warm Season
Ta ^{0}C	Mean	13.23	26.4
	SD	1.73	1.78
	Min	10.21	19.04
	Max	16.6	29.1
Pa mb	Mean	977.79	1389.8
	SD	176.63	185.79
	Min	497.09	766.06
	Max	120.23	1744.41

Table 5.2: Mean and standard deviation of environmental data for both seasons

5.3.2.3 Subjective response to the climatic environment

Sensation

The sensation votes are plotted across the thermal sensation scale (Figure 5.10 and Figure 5.11). The first and most important observation is that over 90% of the subjects votes for the cool season and over 80% of the votes for the warm season were amongst the three central categories, between slightly cool and slightly warm. The main outcome of this observation is that people can be comfortable in a variety of conditions, bearing in mind the difference of temperature ranges they were exposed to during both seasons. The above observations should be compared with the results from the expectation and preference votes for each season.

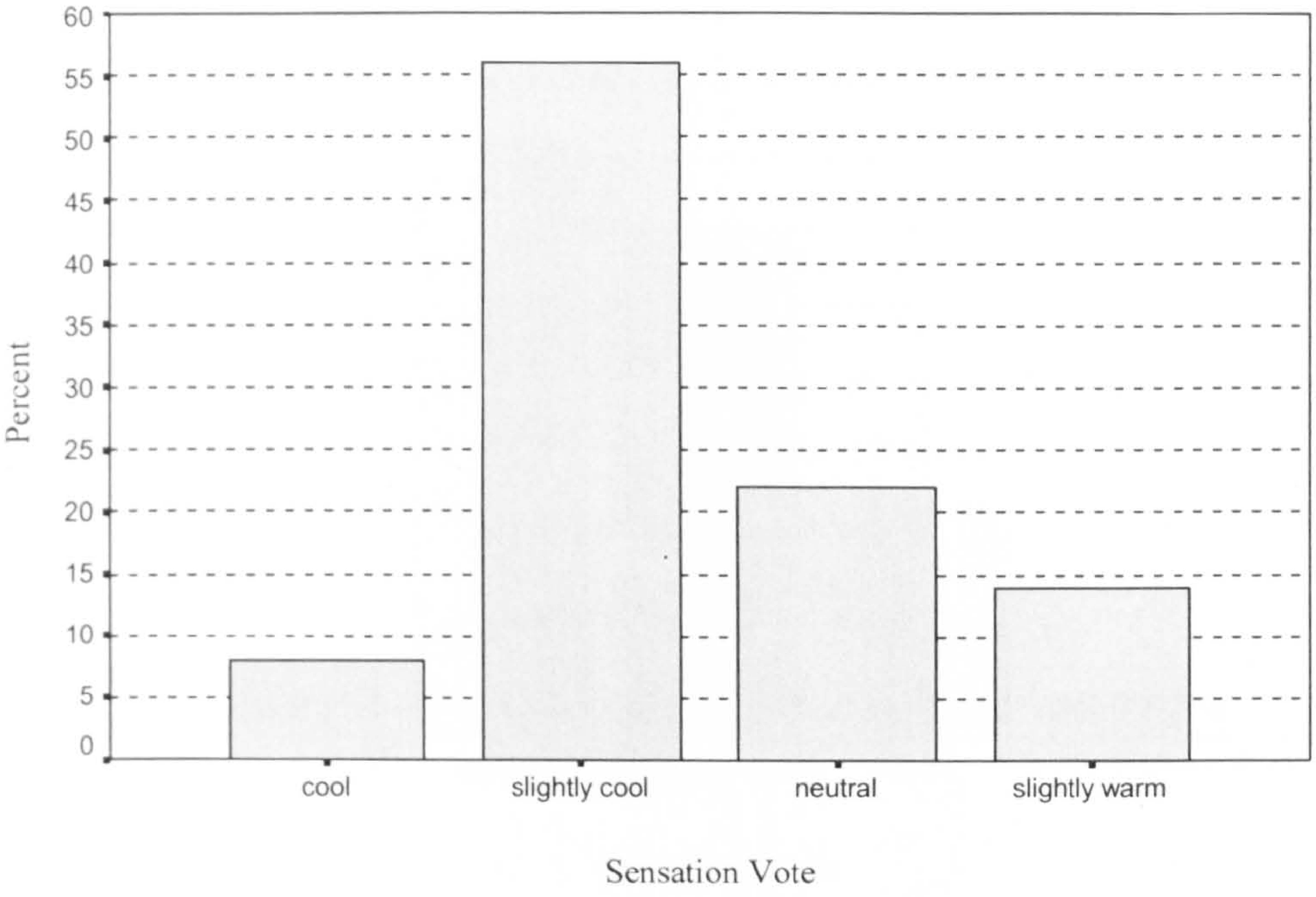


Figure 5. 10: Percentage distribution of sensation votes in the cool season

For the cool season the mean sensation vote was –0.58, "slightly cool" was voted by 56% of the subjects, whereas 22% indicated comfort. 14% of the subjects felt "slightly warm" at the time of interview and 8% "cool". The results were expected to have an inclination towards the cool side of the scale as the survey was conducted in the cool season. For the warm season the mean sensation vote was 0.71. The peak vote with 41% was "neutral", 35% of the subjects indicated "slightly warm" and only the remaining 19% of the votes were for "warm" and "hot" conditions. It is interesting to comment on the fact that during the warm season, only 3% of the subjects indicated feeling "hot", +3 in the ASHRAE scale.

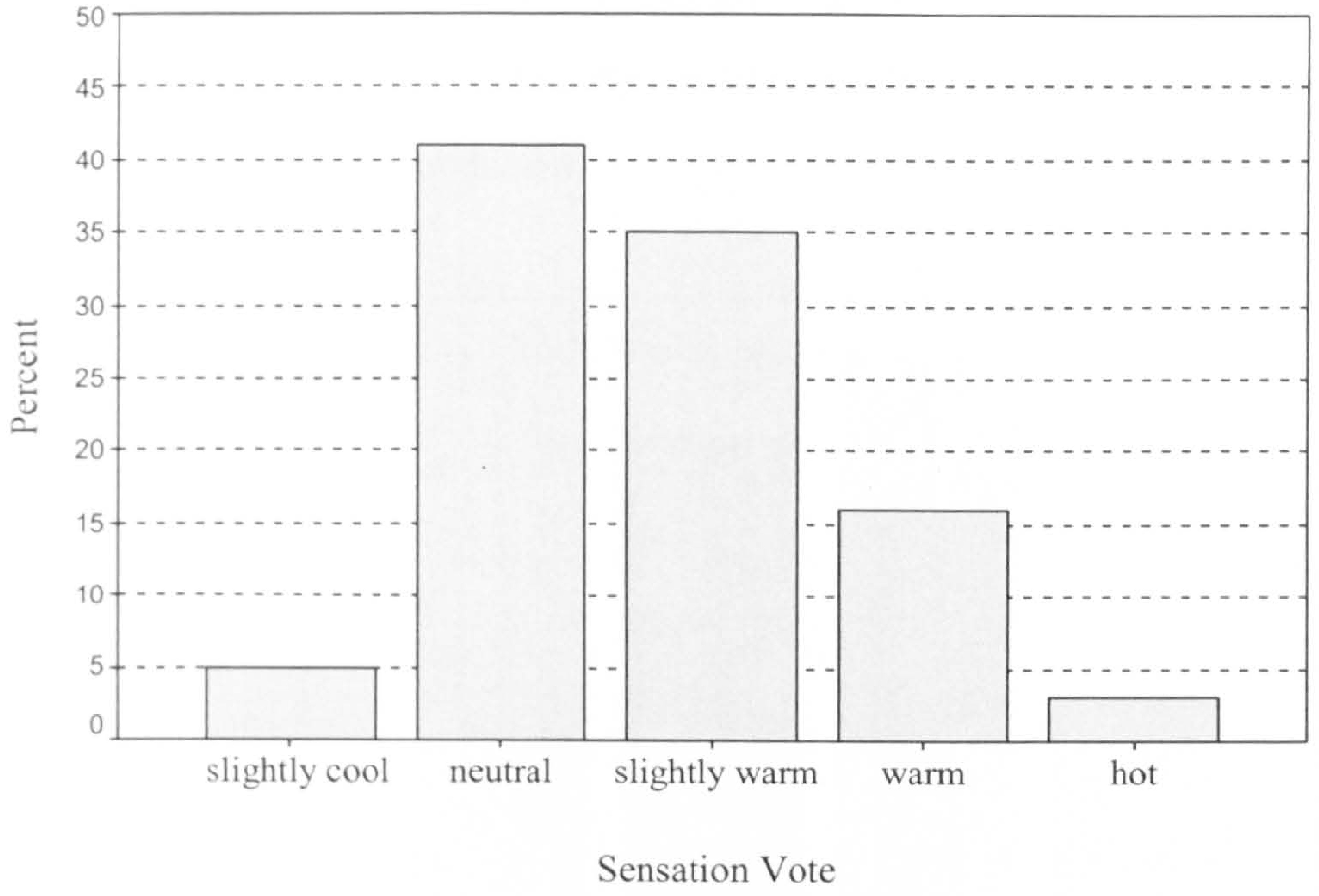


Figure 5. 11: Percentage distribution of sensation votes in the warm season

Expectation

The role of expectation in thermal comfort research was acknowledged in the earlier work of McIntyre (1980) who stated that "a person's reaction to a temperature which is less than perfect will depend very much on his expectations, personality, and what else he is doing at the time". De Dear et. al (1997) argues that although psychological adaptation is the least studied of the three adaptive mechanisms, it might actually play the most significant role in explaining the differences between observed and predicted thermal responses. And this applies particularly in light of different environmental contexts such as environmentally controlled vs. naturally ventilated buildings. He also argues that "*expectation along with habituation, are influenced by one's current thermal experience or one's longer history of experiences with both indoor and outdoor climate*".

The mean expectation vote for the cool season was "slightly cool" (-0.51) whereas the biggest percentage of the subjects (37%) expected to feel neutral (Figure 5.12). There was only 15% of the subjects expected to feel "slightly warm" whereas the cooler part of the scale accounted for 16% of the subjects. The results were again predictable due to the season of the survey was conducted.

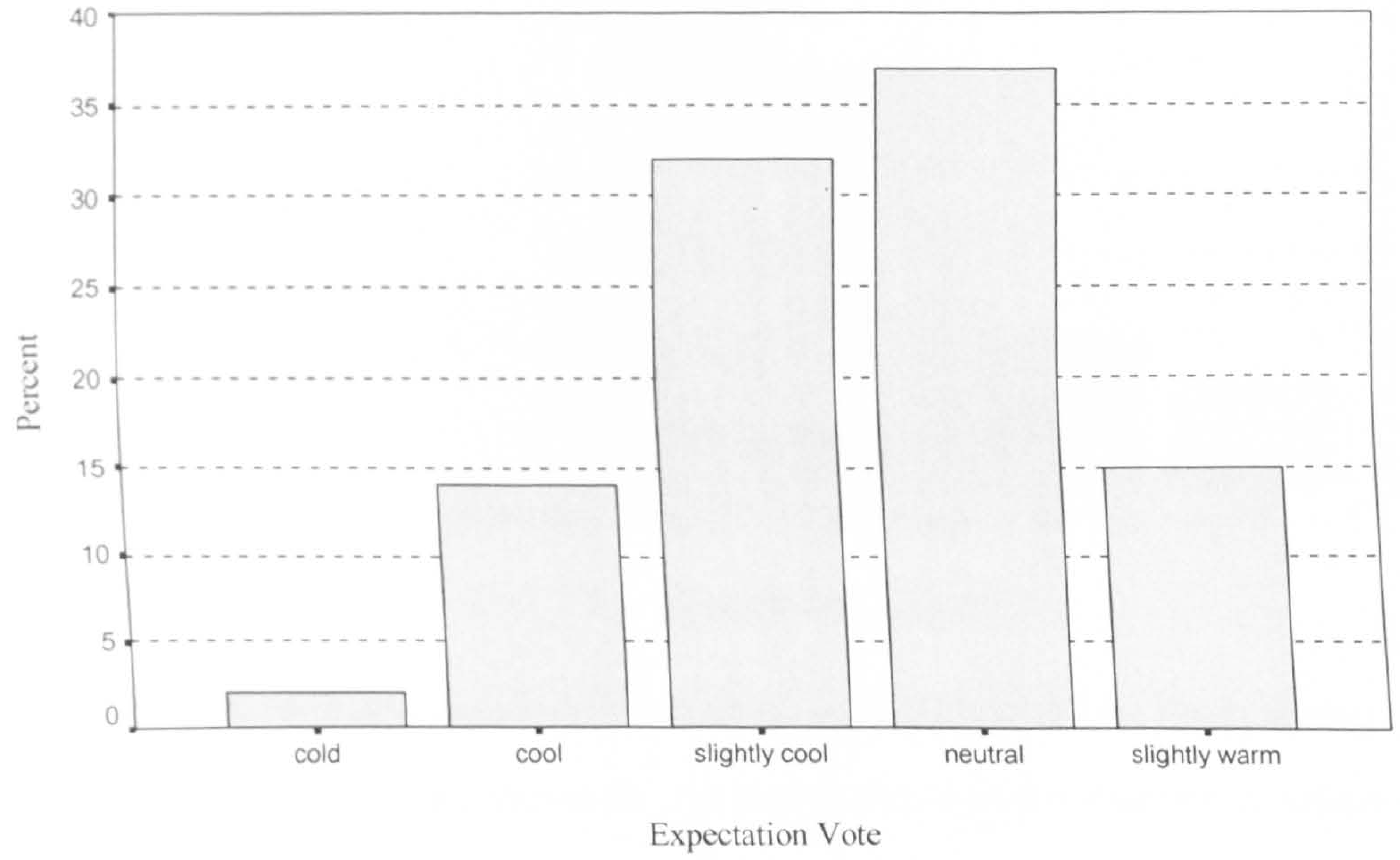


Figure 5. 12: Percentage distribution of expectation votes for the cool season

For the warm season, the mean expectation vote was –0.39, indicating that the majority of the population expected to feel "slightly cool" inside the atrium space. In total 66.5% of the population votes were amongst the three central categories, 24.5% of the votes for the cooler side of the scale and only 9% expected to feel "warm" or "hot" inside the atrium space (Figure 5.13).

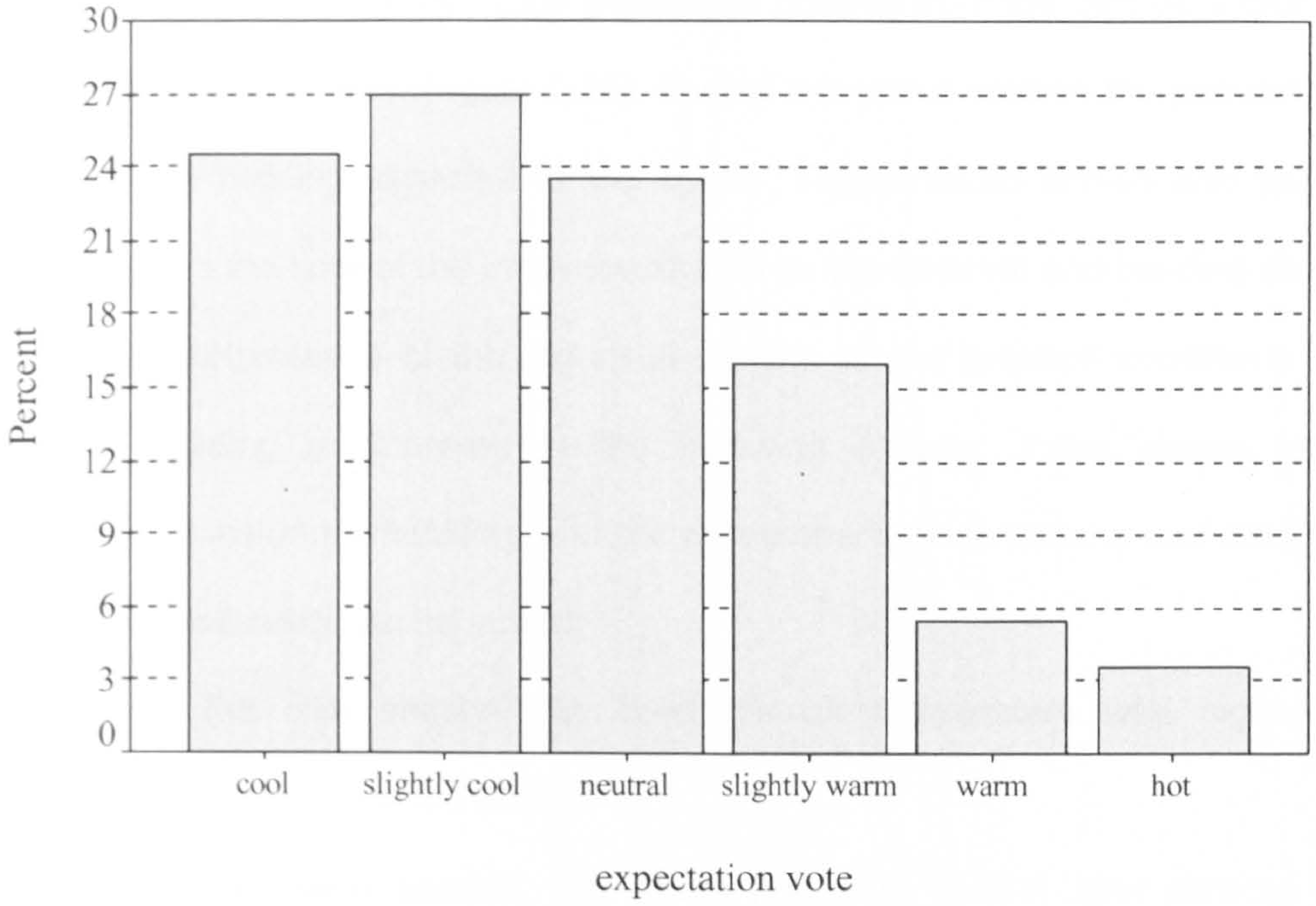


Figure 5. 13: Percentage distribution of expectation votes for the warm season

In the context of this research, the expectations of the thermal conditions inside the atrium from the subjects, especially during the warm season, is of vital importance. There is an extensive knowledge, due to many research and surveys, how people expect to feel in their living or working space. But relatively little knowledge exists on how people expect to feel in places such as an atrium space, which is neither "inside" or "outside". The surveyed atrium functions more as a transitional space between the outside of the University campus and the Philosophic school, as well as between the classrooms and the libraries located in either side of the building. It is a space that the occupants use regularly throughout their daily activities. Therefore it was of particular importance to investigate also the preceding space that each of the respondents was in before coming into the atrium.

The two graphs in Figure 5.14 show the percentage of population indicating the preceding space before entering the atrium for the cool and warm season. An analysis of the subjects' responses in relation to the precedent space they were before entering the atrium shows that the majority of the population coming from the outside expected to feel warmer in the cool season (Figure 5.15). During the warm season the population coming from inside the building expected to feel cooler. These results should also been seen in relationship with the time of the interview as well as the ambient and building climatic data. The thermal performance of the atrium in relation to the external conditions and those inside the building is analysed in the following chapter. From simple temperature measurements inside the building and the researcher's observations and discussion with the users, the following can be stated:

- During the cool season, the building's air temperature was higher than the temperatures inside the atrium.
- During the warm season, the users had little control over devices (such as operable windows, shading devices, fans) to allow them to feel cooler inside the main building, whereas much of the atrium's roof windows were open for natural ventilation.

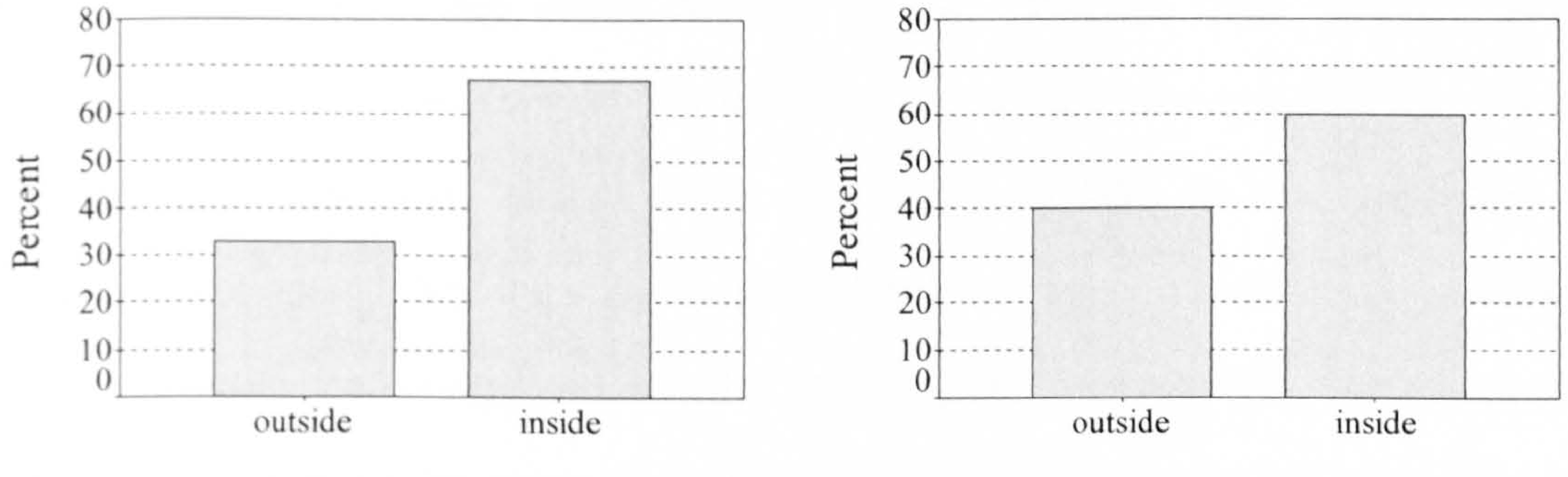


Figure 5. 14: Percentage of population showing the preceding space before entering the atrium for the cool (left) and warm season (right) respectively

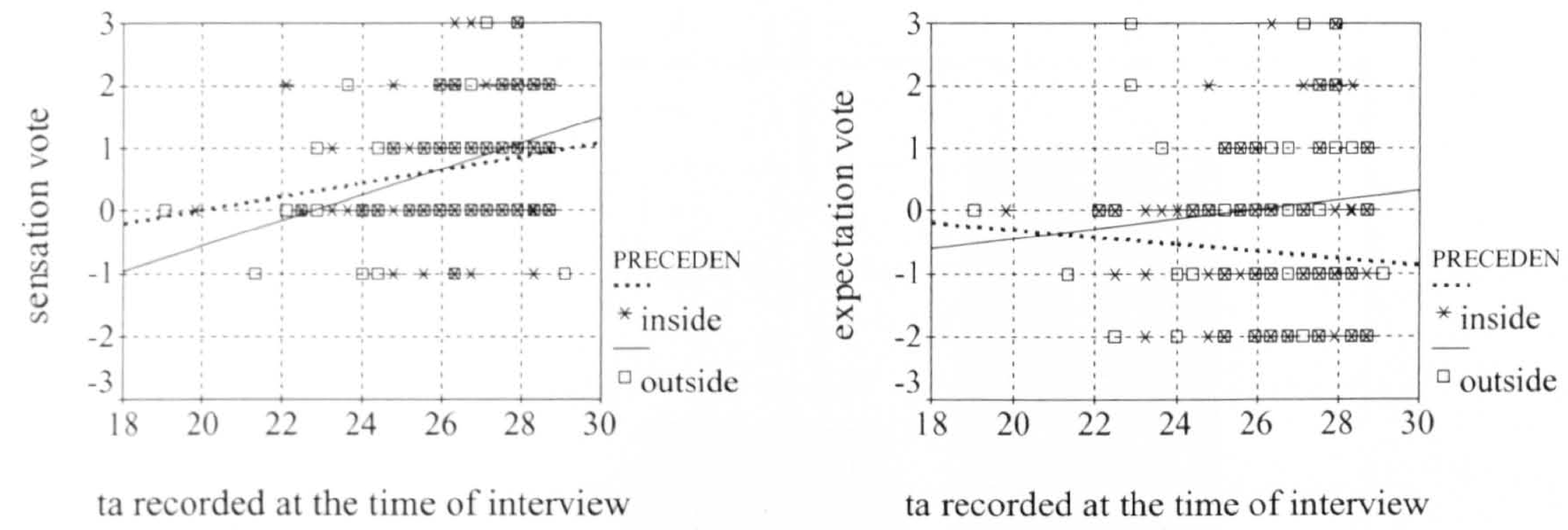


Figure 5. 15: The two graphs show the sensation and expectation votes plotted against temperature at the time of interview and the patterns of the responses according to the precedent space for the warm season.

Responses to the preference votes were on the McIntyre scale. Figure 5.16 shows the preference distribution for the cool season. The mean preference vote was 0.60, the vote for slightly warmer accounted for 62% of the population interviewed. That means that 2/3 of the subjects wanted a change in the thermal environment. 36% vouched for no change and only 2% would prefer to be cooler. These results are also in accordance with what was expected as the voting patterns on the sensation scale indicated that the subjects were cooler than comfort. For the warm season the mean preference vote was -0.67.the peak vote was "cooler" which accounted for 68% of the responses. That represents yet again 2/3 of the subjects that wanted a change in the thermal environment. 31% vouched for no change and only 1% would prefer to be warmer. Accordingly, since the voting patterns on the sensation scale that was biased towards the warm side of the scale, the same percentage of people vouched for a cooler environment (Figure 5.17). The preferred temperature thus was lower than the neutral temperature and this is supported by the statement from Nicol et al (1993) that: "*the preferred temperature is below the comfort temperature in hot conditions*".

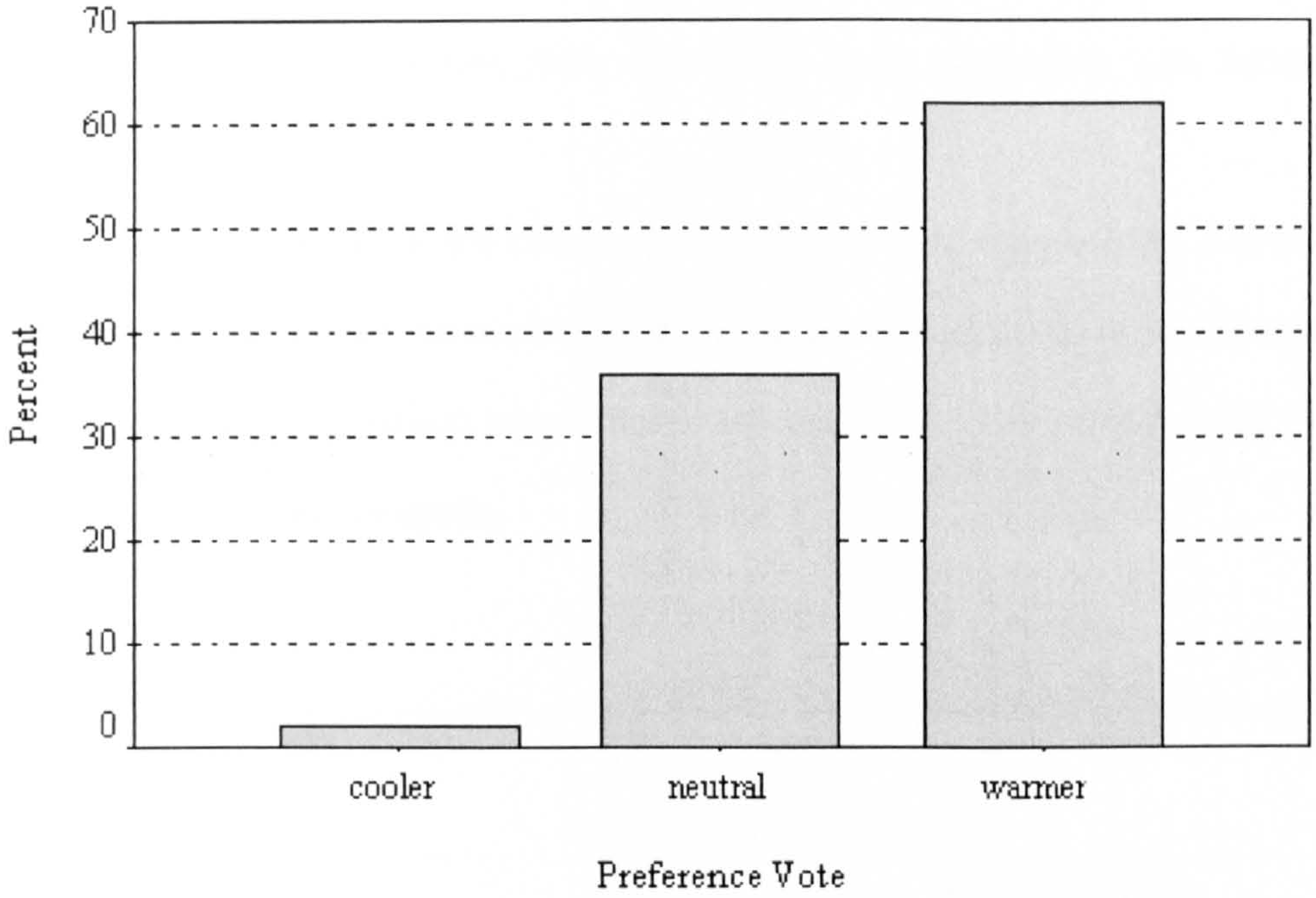


Figure 5. 16: Percentage distribution of preference votes in the cool season

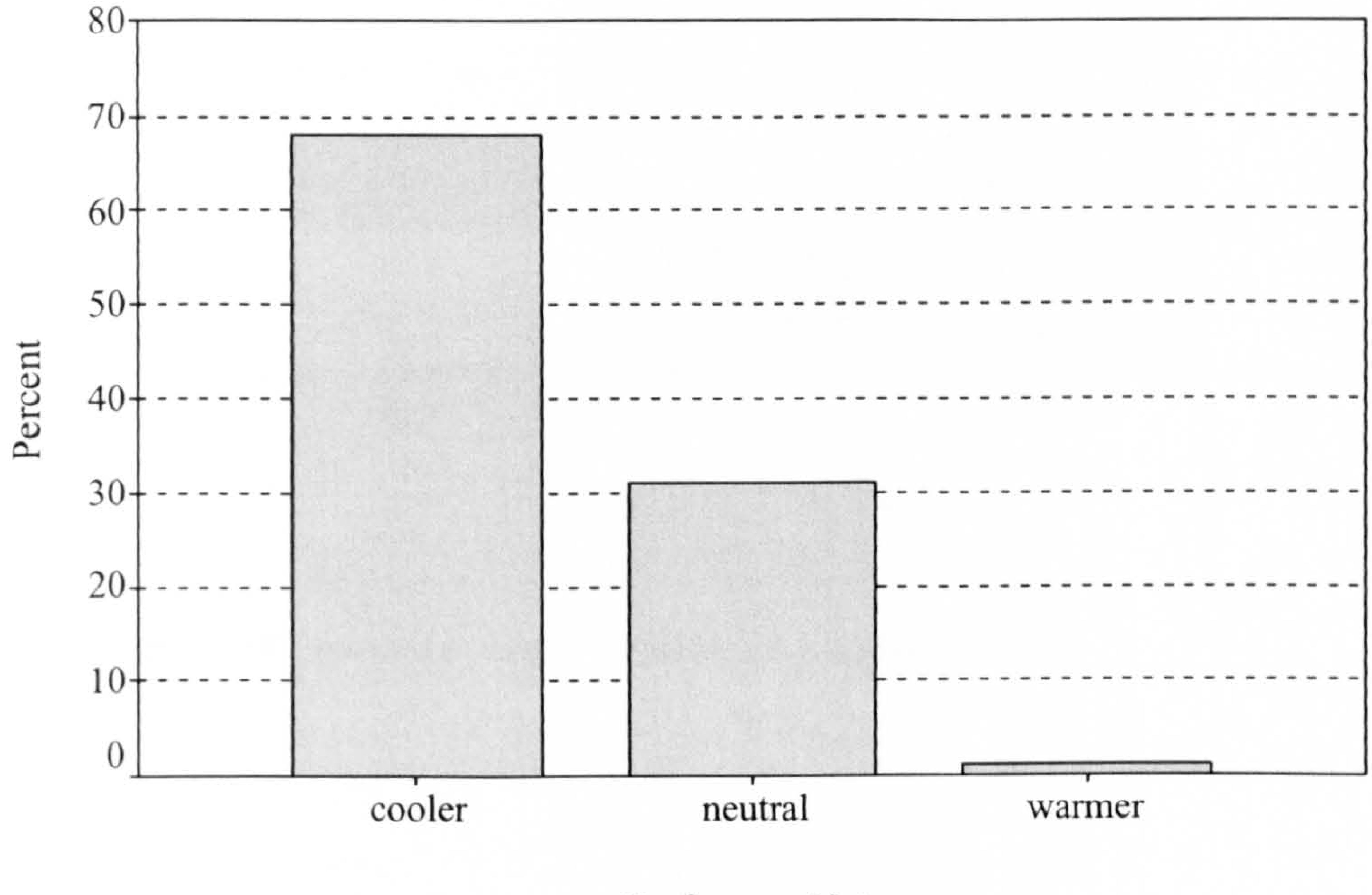


Figure 5. 17: Percentage distribution of preference votes in the warm season

Subjects indicated their feelings in terms of humidity and air movement on a three-category scale, as they may find more than three categories can become difficult to understand.

Humidity patterns are shown in Figure 5.18 and Figure 5.19. For the cool season subject votes were 79% on humid point. In the warm season 57.5% indicated their vote on the middle category, which is just right, and 35.5% on the humid. That was due to the humidity during both seasons.

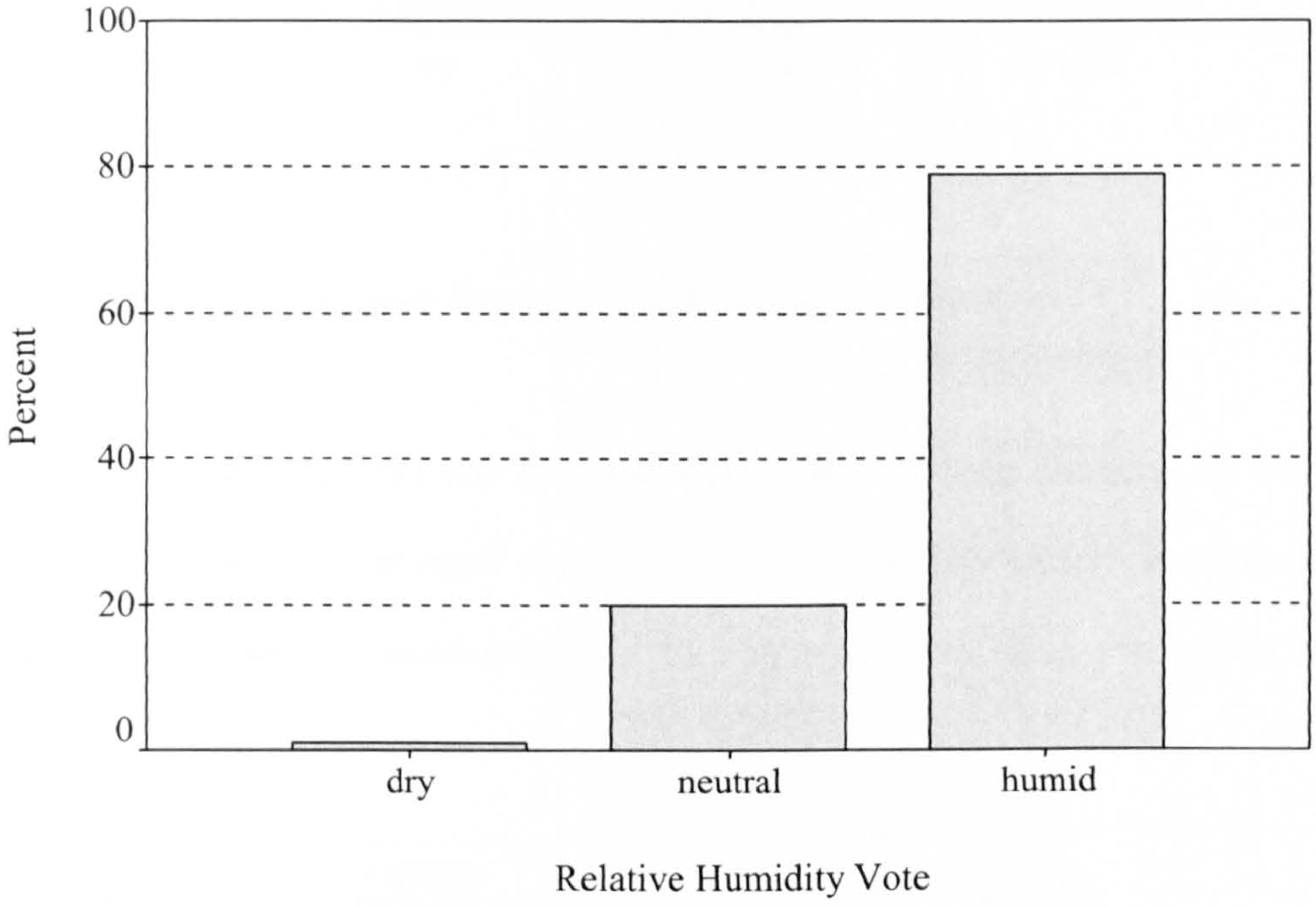


Figure 5. 18: Relative humidity votes for the cool season

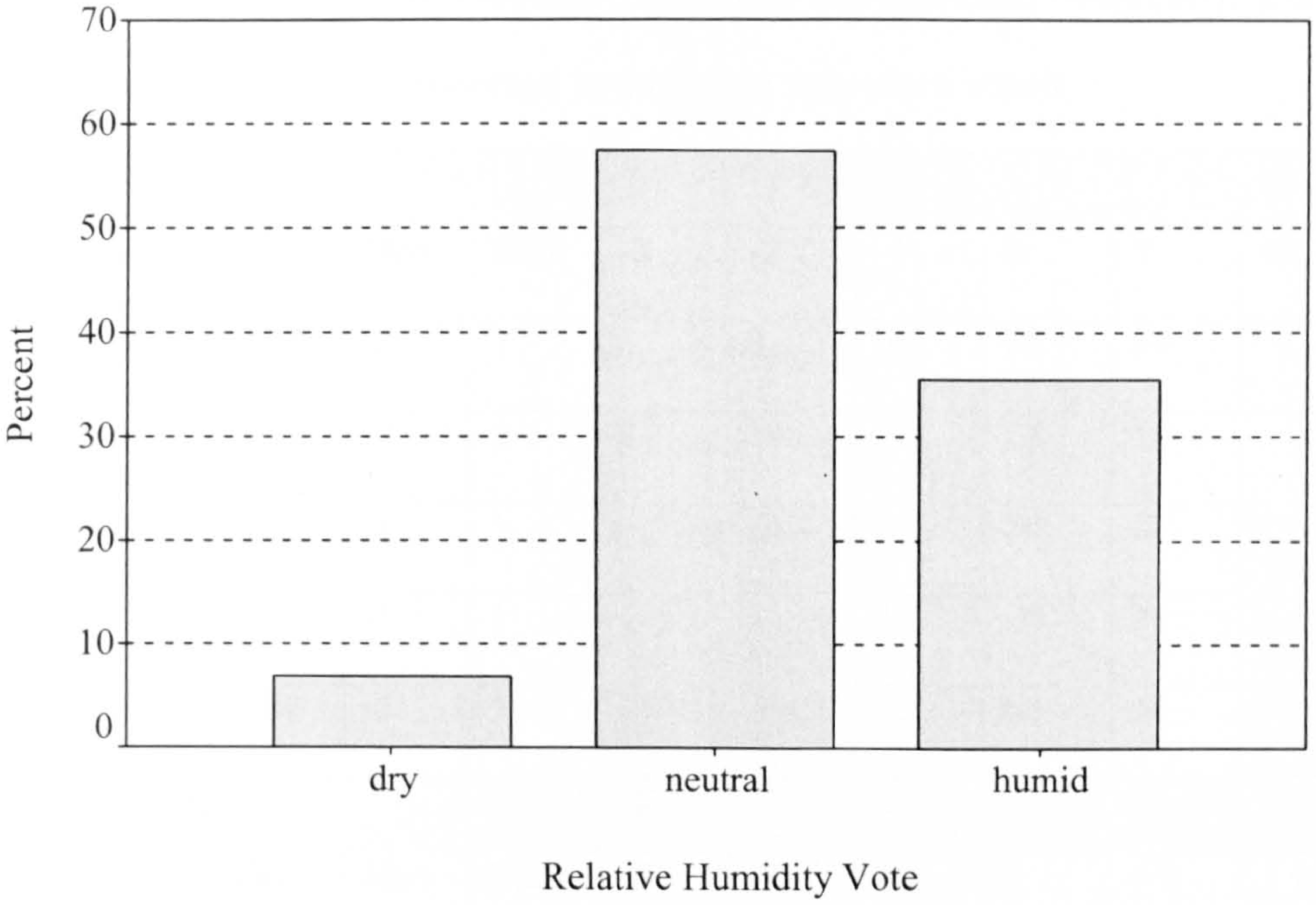


Figure 5. 19: Relative humidity votes for the warm season

Figure 5.20 shows the air movement votes for both seasons. In the cool season most people were in "just right" condition in terms of airflow, which accounts for 56% of the votes. The subjective assessment of the air movement was still (49%) for the warm season.

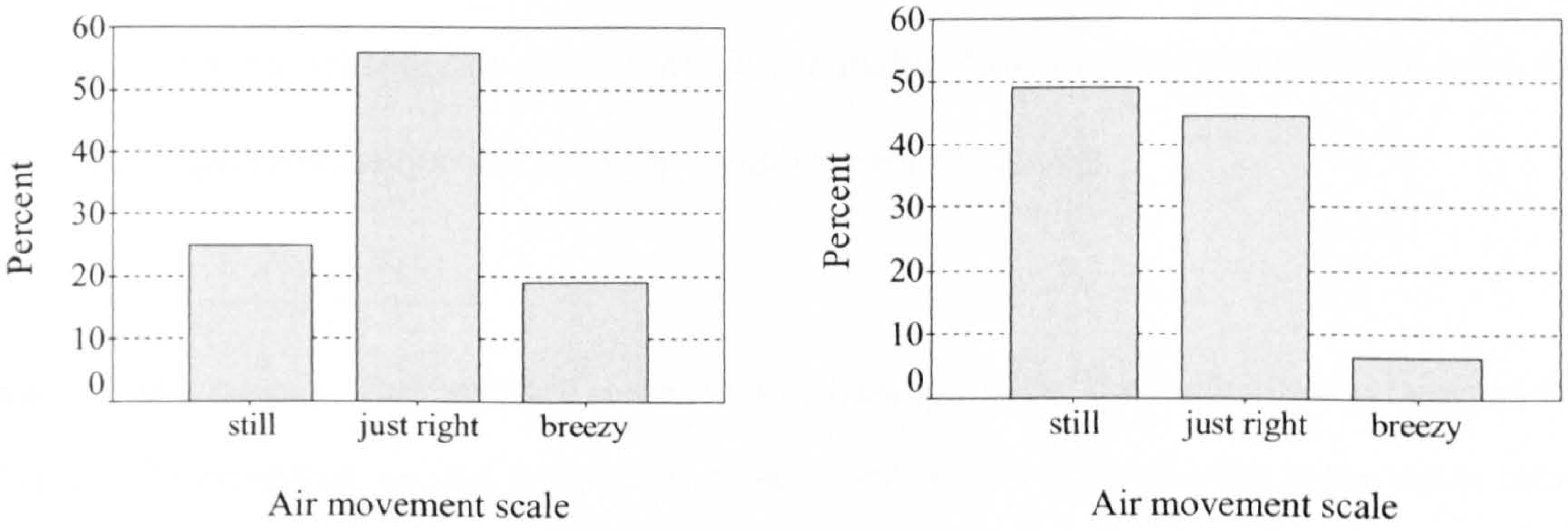


Figure 5. 20: Air movement votes for the cool (left) and the warm season (right)

Table 5.3 summarizes the mean, min, max and standard deviation of the subjective responses as well as the percentage in the scale they were voted.

Cool Season					**%**					
	Mean	**SD**	**Min**	**Max**	**-3**	**-2**	**-1**	**0**	**1**	**+2**	**+3**
Sv	-0.58	0.83	-2	1		8	56	22	14		
Ev	-0.51	0.98	-3	1	2	14	32	37	15		
Pv	0.60	0.53	-1	1			2	36	62		
RHv	0.78	0.44	-1	1			1	20	79		
Av	-0.6	0.66	-1	1			25	56	19		
Warm Season					**%**						
	Mean	**SD**	**Min**	**Max**	**-3**	**-2**	**-1**	**0**	**+1**	**+2**	**+3**
Sv	0.71	0.90	-1	+3			5	41	35	16	3
Ev	-0.39	1.34	-2	3		24.5	2	23.5	16	5.5	3.5
Pv	-0.67	0.49	-1	1			68	31	1		
RHv	0.28	0.59	-1	1			7	57.5	35.5		
Av	-0.43	0.61	-1	1			49	44.5	6.5		

Table 5. 3: Tabulation of Sensation, Expectation, Preference, Humidity and Air movement votes for both seasons.

In order to investigate further the relationship between air temperature and the subjective responses, series of boxplots[1] graphs were produced.

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[1] Structure of a boxplot: The box itself represents that portion of the distribution falling between the 25th and 75th percentiles, i.e. the lower and upper quartiles. The xth percentile is the value below which x% of the distribution lies. The thick horizontal line across the interior of the box represents the median. The vertical lines outside the box (whiskers) connect the largest and smallest values that are not categorised as outliers or extreme values (Kinnear, Gray, 2000).

Boxplots are specifically useful for identifying extreme values in data sets and the range of values as well as the symmetry of their distribution.

The comfort votes were plotted against air temperature at the time of the interview for the cool season as shown in Figure 5.21. As it can be seen from the graph, the lines that correspond to the median values rise as the air temperature increases. The air temperature distribution for "cool" sensation is the less symmetric, whereas the "slightly cool" sensation has the wider distribution of temperatures (between 11^{0}C and 14^{0}C).

Expectation and preference votes for the cool season were also plotted against air temperature at the time of interview. Figure 5.22 shows clearly that there is no apparent significant relation to expectation votes and the thermal conditions at the time of interview; even when people are exposed to the same air temperature, the expectation of the comfort level within a space can vary for every individual.

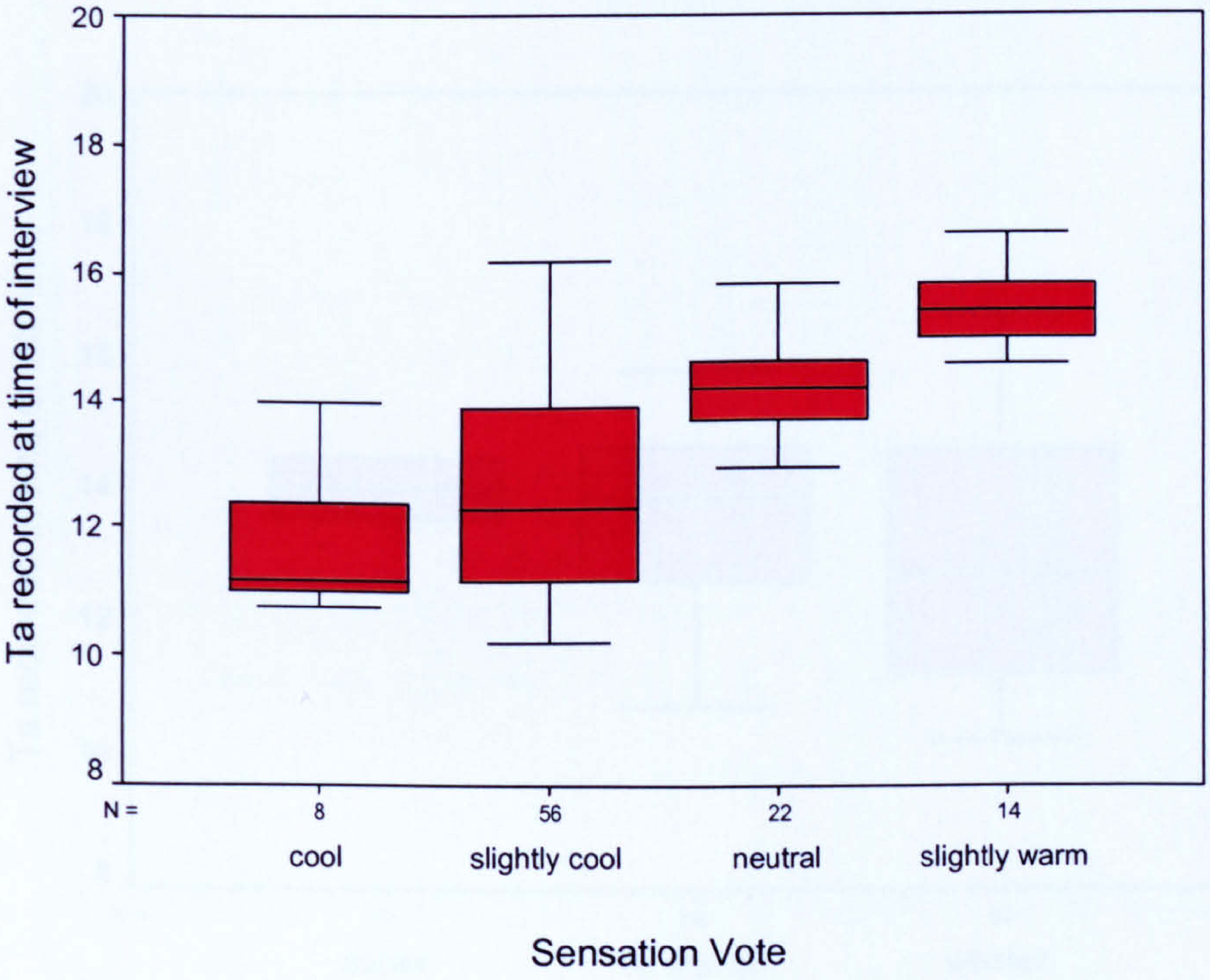

Figure 5. 21: Boxplot of sensation votes on air temperature in the cool season

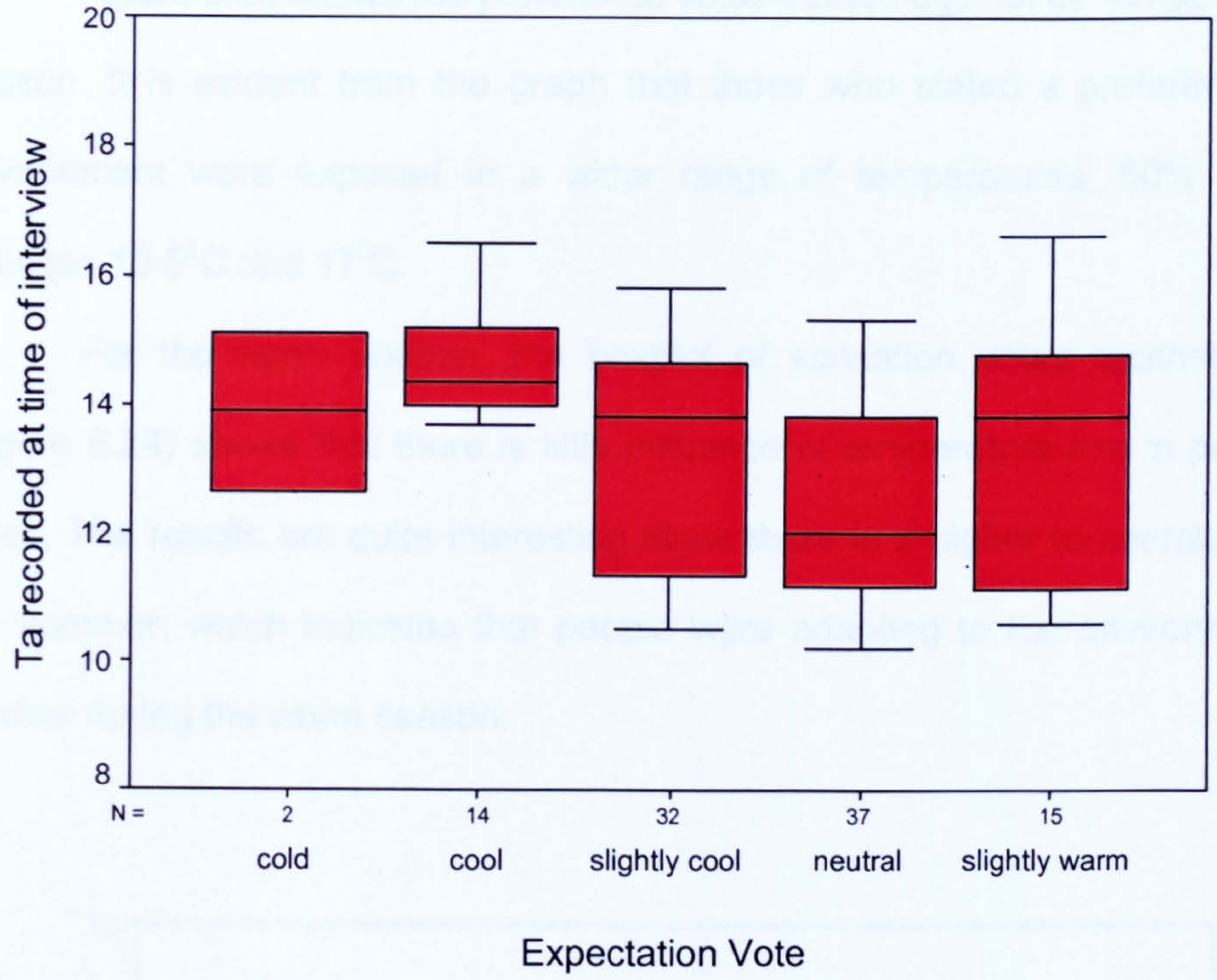

Figure 5. 22: Boxplot of expectation votes on air temperature in the cool season

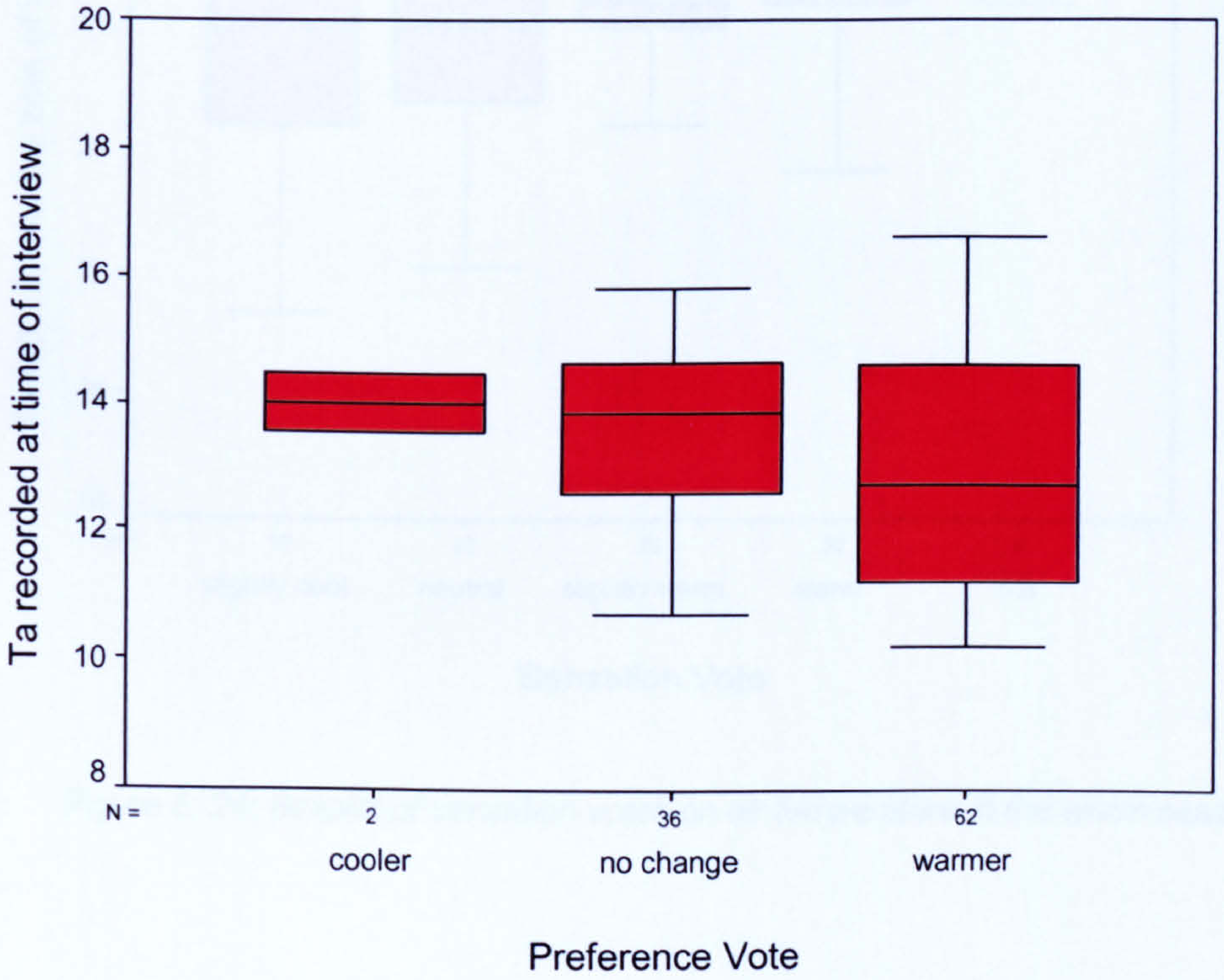

Figure 5. 23: Boxplot of preference votes on air temperature in the cool season

Figure 5.23 shows the preference votes plotted against air temperature for the cool season. It is evident from the graph that those who stated a preference for a warmer environment were exposed in a wider range of temperatures, 50% of which ranged between 10.5^{0}C and 17^{0}C.

For the warm season, the boxplot of sensation votes against air temperature (Figure 5.24) shows that there is little influence of temperature rise in people's sensation votes. The results are quite interesting since there is a higher temperature fluctuation for the summer, which indicates that people were adapting to the environmental conditions quicker during the warm season.

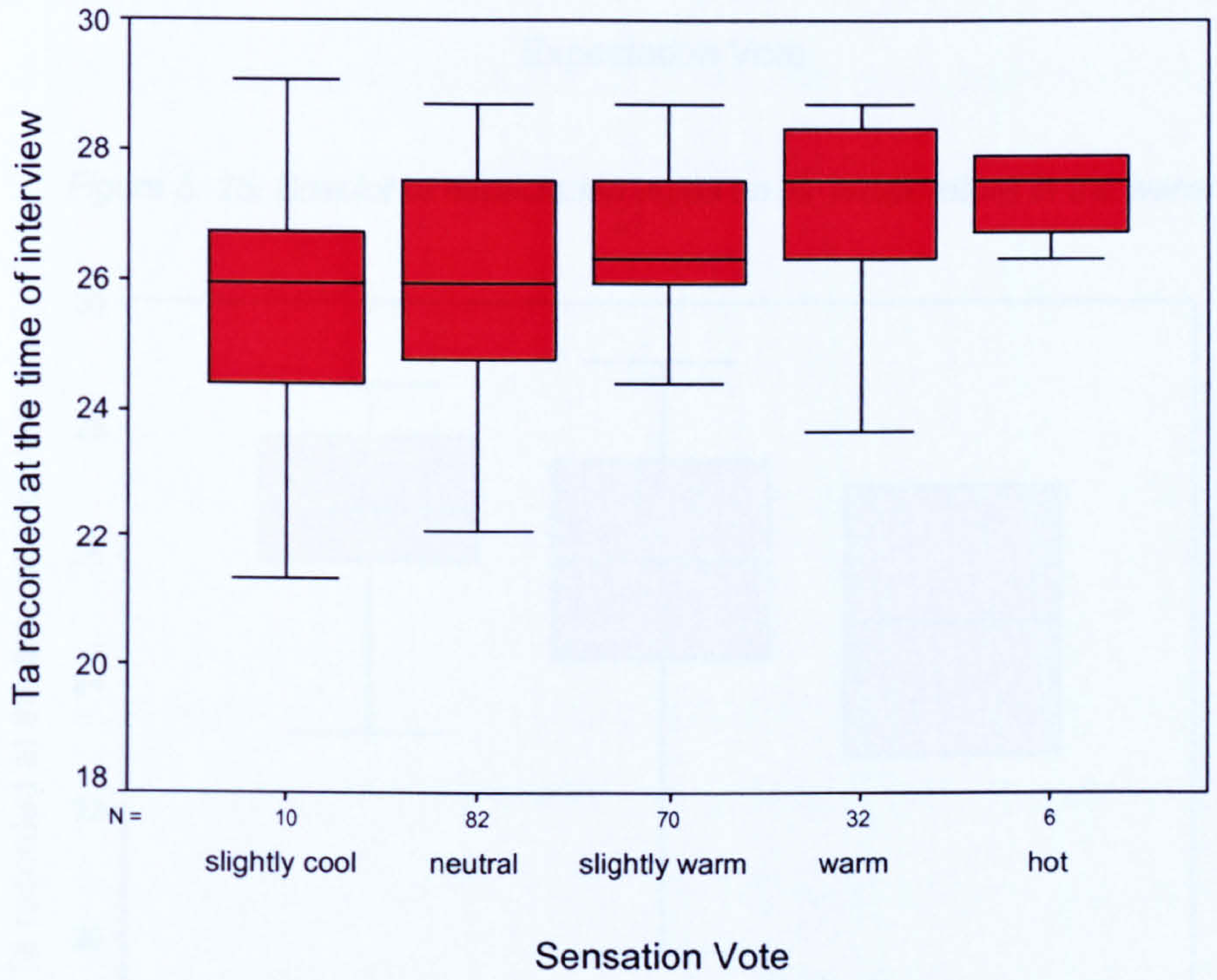

Figure 5. 24: Boxplot of sensation votes on air temperature in the warm season

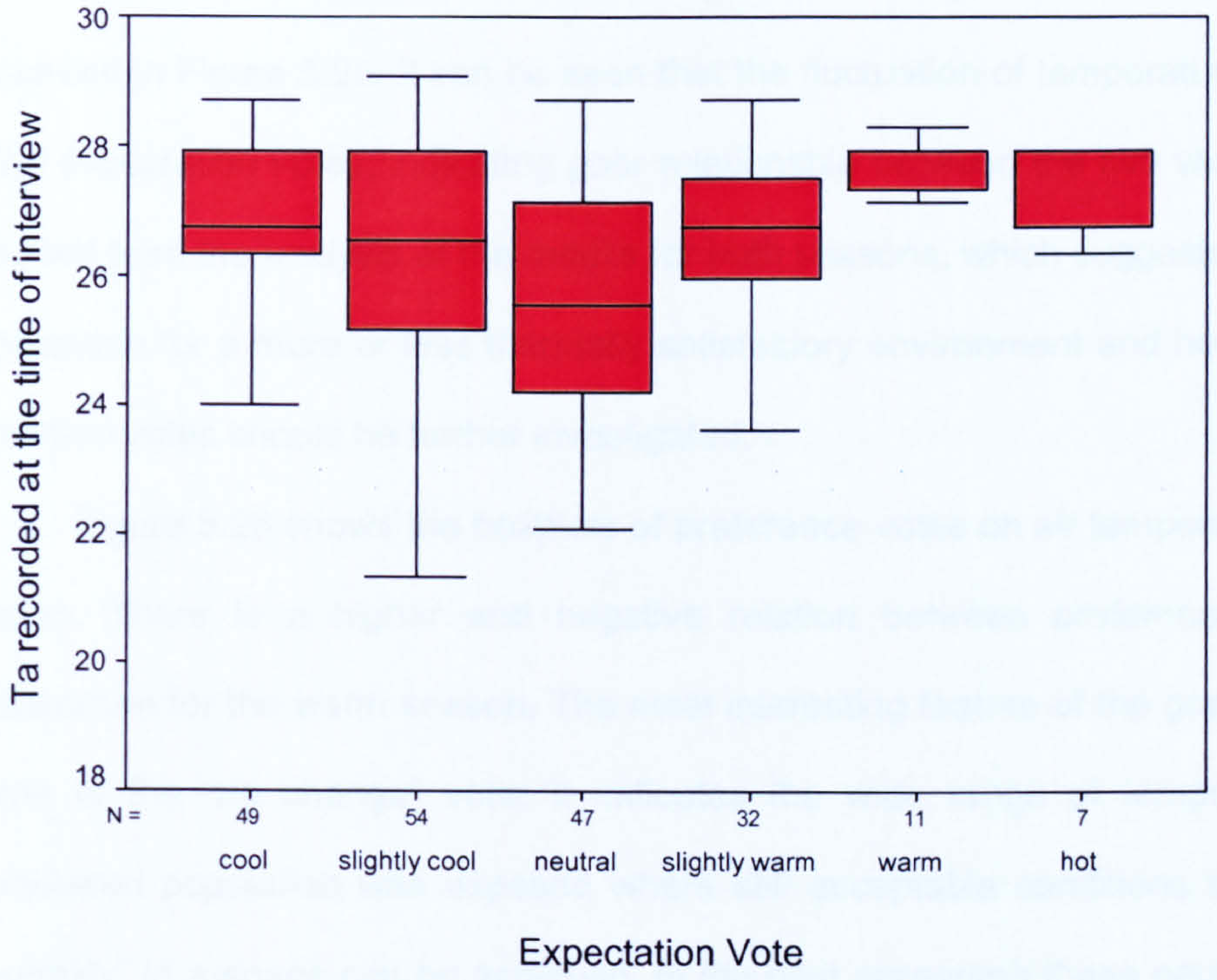

Figure 5. 25: Boxplot of expectation votes on air temperature in the warm season

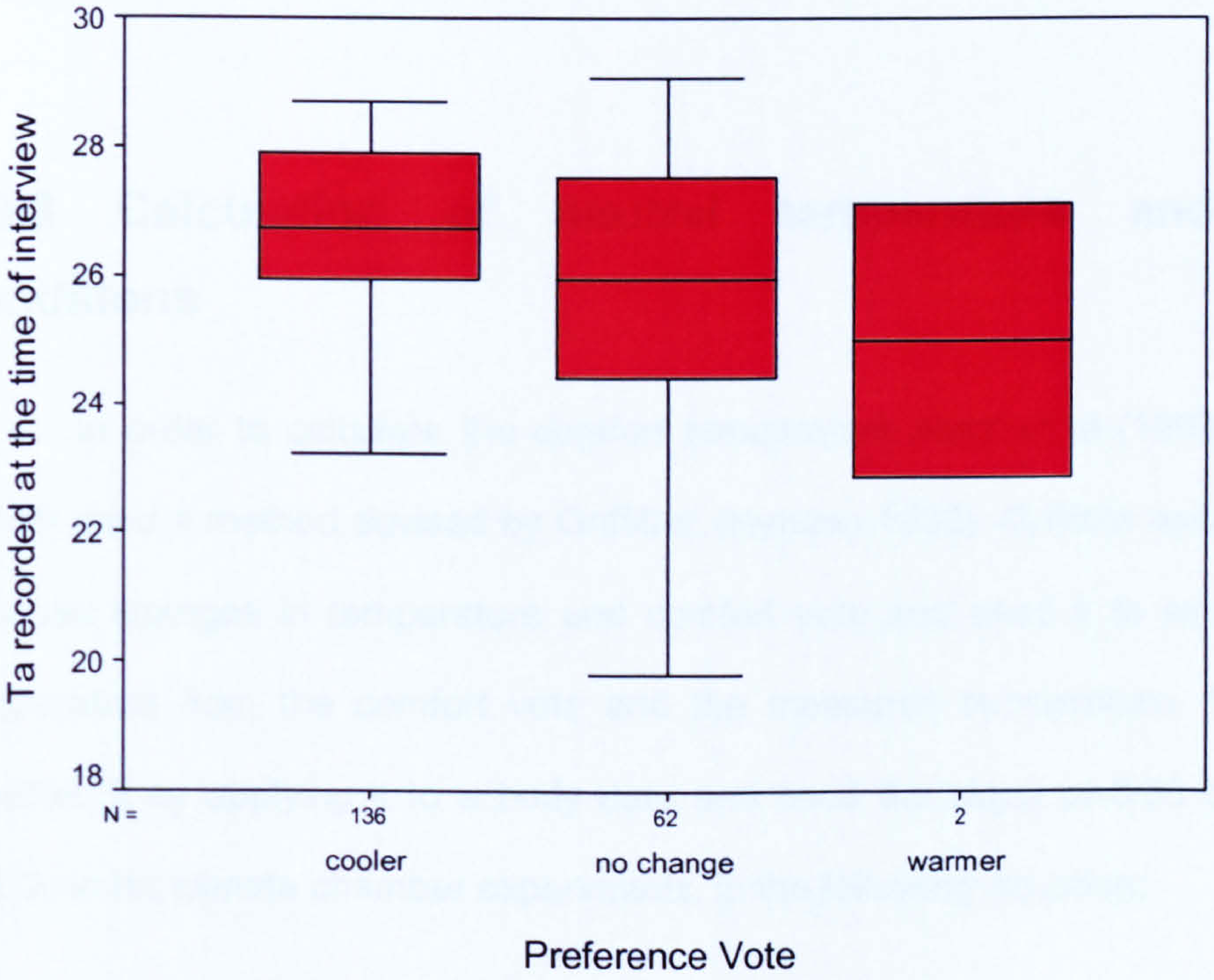

Figure 5. 26: Boxplot of preference votes on air temperature in the warm season

The boxplot of expectation votes against air temperature in the warm season is presented in Figure 5.25. It can be seen that the fluctuation of temperature is not reflected in the expectation votes, indicating poor relationship between the two variables. That was detected from the analysis of the results for both seasons, which suggests that the issue of expectation for a more or less thermally satisfactory environment and how this affects the sensation votes should be further investigated.

Figure 5.26 shows the boxplots of preference votes on air temperature in the warm season. There is a higher and negative relation between preference votes and air temperature for the warm season. The most interesting feature of the graph is the skewed shape of the "no change" vote; it indicates the wide range of temperatures that the interviewed population was exposed where still acceptable conditions and the sense of "neutrality" in a space can be achieved. In the next paragraph these neutral temperatures and acceptable conditions for both seasons will be defined.

5.3.3 Calculation of neutral temperature and acceptable conditions

In order to calculate the comfort temperature Nicol et al (1993) and Humphreys (1976) used a method devised by Griffiths' (Hensen 1990). Griffiths assumed equivalence between changes in temperature and comfort vote and used it to estimate the comfort temperature from the comfort vote and the measured temperature. Nicol et al (1993) modified it by applying it to a body data and used the slope of 0.33 derived by Fanger (1972) in his climate chamber experiments, in the following equation:

$$Tc = Tgm + (4 - Cm)/ a^* \qquad (5.3)$$

Where: Tc is the comfort temperature

Tgm is the mean internal temperature

Cm is the mean comfort vote

a* is the slope of the regression line (0.33)

The above equation predicts "the average comfort temperature to which the population is adapted", Nicol (1999). This method applies when the mean comfort vote is within 2.5 –5.5 range. Nicol et al (1996) justified the use of the climate chamber slope that "it gives the temperature at which the subject is adapted at the time of voting".

The following table shows the relationship between the expectation and sensation votes used in the survey, and the scale of their representation in the equation.

Table 5. 4: Scale 0-7 on scale (+3)– (-3)

Cold	Cool	Slightly Cool	Comfortable (Neutral)	Slightly Warm	Warm	Hot
-3	-2	-1	0	1	2	3
1	2	3	4	5	6	7

From equation 5.3 the neutral temperature for the cool season was 14.98^{0}C and for the warm season 24.22^{0}C.

Thermal comfort requirements are recommended (ISO 1995) for spaces for human occupancy. As an accepted method for predicting boundaries of comfort conditions and according to ISO 7730 – 1995, the range of PMV (predicted mean votes) between (-1) to (+1) on sensation votes on ASHRAE seven point scale would result in 75% of subjects feeling satisfaction with their thermal environment. For satisfaction of 90% of subjects the range of PMV would correspond to the following criteria:

$-0,5 < PMV < + 0,5$

In line with these acceptable methods, the neutral temperatures and acceptable conditions for both seasons are shown in table 5.5.

	Neutral temperature	**Acceptable Condition (75%)**	**Acceptable Condition (90%)**
Cool Season	14.98 ^{0}C	11.98-17.98	13.47 – 16.49
Warm Season	24.22 ^{0}C	21.22-27.22	22.71-25.73

Table 5. 5 Neutral temperature and comfort zone for both seasons

5.4 Evidence of adaptation

There are a number of ways in which people adapt to variations in temperature. The ones recorded by observation in this study are:

- Changed position, moved around the space
- Changed their clothing to suit prevailing conditions
- Changed conditions by using environmental controls to their disposal

Adaptive model implies an environment design method taking into account the behavioural and psychological adaptation of the occupants for the particular environment. This approach seems effective in semi-outdoor spaces designed for voluntary occupancy where occupants seek environments differing from outdoors.

Only surveys form winter and summer are analysed here but perception of thermal environment was affected by contexts such as the level of environmental control and season. High thermal acceptability (-1<PMV<+1), rate of more than 75%was observed for both seasons, supposedly due to the fact that the occupants were given higher adaptive opportunity than indoor spaces designed for long-term occupancy, with freedom to stay or leave the environment at their will. However, seasonal difference of thermal sensation was observed in the building.

The wide, low for the cool season and high for the warm season, comfort zone is an evidence that occupants adapt to the thermal environment of the glazed courtyard: by utilizing behavioural adjustments (clothing, metabolic rate, change of position, even the choice to leave the space, etc.) the results show that occupants were able to accept a thermal environment that in established standards for thermal environments would be considered cold (for the cool season) and hot (for the warm season). The results also indicate that behavioural adjustment and expectation have an evident influence in the process of thermal adaptation. That may also have a strong link with the use of the space as well as with the fact of being a naturally ventilated space. Brager et al (1998), in a review on the topic of thermal adaptation in the thermal environment, showed that occupants in naturally ventilated buildings had more relaxed expectations and were more tolerant of temperature swings, while also preferring temperatures that tracked the outdoor climatic trends.

In the current study, the glazed courtyard is a genuine free-running transitional space that could play a major role in the thermal scenario of the whole building. It favours a subliminal environmental adaptation that enable the occupant to avoid abrupt environmental changes that could lead to discomfort, especially considering the large ambient temperature fluctuations in both seasons. This is a key observation, especially considering matters of sustainability as well as energy consumption that are worthy of further investigation.

5.5 Observations & Conclusions

A thermal comfort survey in an atrium building at the University of Ioannina in Greece during the winter 1999-2000 and the summer 2000 was carried out in conjunction with a thermal comfort questionnaire.

The current study is not a complete thermal comfort survey. Rather it relates to the design element's effect on temperatures occurring inside the atrium space. It is therefore more an environmental effect than a comfort survey. It looks into design parameters that influence the thermal environment, internal atrium conditions –mainly expressed with air temperature and the people's behaviour and reaction and sensation. Particularly in an atrium is the general sensation, which is very difficult to be described.

Because in Mediterranean climate spring and autumn are short seasons, measurements took place during the harsh and more distinctive seasons of winter and summer.

Environmental parameters were measured providing data sets of air temperature, relative humidity and light intensity in conjunction with external weather measurement over a period of 3 months.

The availability and appropriate use of controls in a building allows occupants to modify the internal environment (Nicol 1999). In naturally ventilated buildings, control over indoor temperature and ventilation can be obtained by using commonly available controls such as operable windows, ventilators, doors, etc. In more extreme conditions, coolers, fans or heaters may be used. In the present survey, the use of controls was observed and recorded by the researcher.

Staying at the atrium was generally a pleasant experience. During the evening and whenever the outside temperatures were not extremely high, there was a slight and pleasant breeze. Sometimes when the outside temperature was quite high, humidity was quite high as well. But there was no difficulty with glare whatsoever.

Negativity towards the atrium was mainly from the staff and generally from older people. Many of the people that were being interviewed (mainly staff), had a negative opinion on the covering the courtyard that took place to create the glazed courtyard. It's quite contradictory the fact that many of the people that have been complaining about the courtyard state it has become darker since the roof was added, yet used their curtains for long periods.

Even though many people complain that by covering such spaces there is limited or no feasibility for using natural fresh air, by observing and researching similar spaces (some of which are uncovered) the conclusions (mainly concerning the warm season) are that:

- In most of the adjacent rooms the blinds were used excluding natural light and artificial light was used instead.
- The windows were closed, therefore not using natural ventilation and cooling was achieved exclusively by the use of air-conditioning.
- The majority of the open courtyards visited could be described as being aesthetically unpleasant and unexploited spaces, that were equally difficult to occupy in winter (due to rainfall and low temperatures) as well as during summer (due to excess heat and exposure to high solar radiation).

The subjective judgments are always affected by the preceding environmental conditions or reference level. It seems to be a very important and decisive factor in the subject's questionnaire. Expectation also plays a large role on how people experience comfort. In some cases, an expectation for lack of comfort may lead to a greater tolerance for temperature variation. First it has to do with the fact that if the subject has a knowledge that an enclosed space-covered with glass- would probably cause overheating problems, then he/she would probably have a higher expectation mark. Another subject would feel that since there is an enclosed space it is probably environmentally controlled and would probably expect to find it cooler. Most definitely the subjects opinion has to do with the place they were just before entering the atrium space. If they were coming from outside the building then they would find it pleasantly cool, since there is quite a long unshaded road to walk to the School of Philosophy. Also from the analysis of the results it can be stated that:

- During the cool season, the atrium space was considered a cooler space than the rest of the building. However, it was used as a circulation space, and the analysis of results show a low level of discomfort even in temperatures of 10^{0}C.
- During the warm season, the users circulating in the atrium space coming from inside the building felt warmer than they expected.
- The wide, and low for the cool season and high for the warm season comfort zone is the result of adaptation, which results in low discomfort in winter when subjects are adapted to cold, and in summer when they are adapted to hot conditions.

Although little work has been done on thermal comfort in such environments, it is likely that people expect environments differing from indoors, and the thermal comfort condition may differ from that of indoor steady state. It was concluded that the relationship between expectation and sensation should be explored further in a future survey in atrium buildings.

Remarks and comments were written on the questionnaire where the subjects felt there was a void for expressing their own, uncoded opinion about the way they feel and the things they would to feel better.

The people are using the atrium space in order to circulate through the adjacent buildings. The two larger buildings being divided into two separate departments enhance that even more. The people that do not wear jackets walk faster.

Testing in actual spaces provides an opportunity to measure interactive effects of several variables determining energy consumption as well as comfort. Only through such measurement can real building system schedules, occupant use and control be realized. Successful integration of building design strategies, in relation to thermal comfort and climate, will also be studied in the following chapters.

From the current study it can be reckoned that glazed spaces with no environmental control can be found acceptable but the expectations of the thermal environments to be found by building users introduces an additional complexity for the designer.

The next chapter is the parametric analysis of various models of atrium buildings in an attempt to answer the questions raised in the first chapter of the thesis: which factors to take into consideration when designing atrium spaces in a Mediterranean climate.