Climate and Energy Responsive Housing in Continental Climates

The Suitability of Passive Houses for Iran's Dry and Cold Climate

Farshad Nasrollahi

Farshad Nasrollahi was born in 1977 in Shahrekord, Iran. He passed his secondary education in a high school considered for more intelligent students, and got a diploma in 1995. In 2002 he obtained an M.A. in architecture from the Faculty of Arts and Architecture of the state Yazd University in Iran. His thesis has won the highest rank in the first Festival of Architecture and Urbanism of the Faculty of Fine Arts, Tehran University. Nasrollahi has worked for four years as a lecturer in the departments of Architecture and Civil Engineering of the Shahrekord branch of Azad University. In November 2004 he started his doctoral studies in the field of Energy and Architecture under the guidance of Prof. Dr. Peter Herrle (in Habitat Unit) and Prof. Claus Steffan (in the Unit of Building Technology and Design), Berlin University of Technology, where in the meantime he has worked as a research assistant for some periods in 2006-2008. In 2009 he defended his doctoral thesis with a "very good" rank. Since 2008 he has worked as a research associate in his unit. Dr. Nasrollahi has published many scientific papers in energy and architecture.

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ISBN 978 3 7983 2144 1

∞ ***Gedruckt auf säurefreiem alterungsbeständigem Papier***

Druck/Printing docupoint GmbH Magdeburg

Vertrieb/ Universitätsverlag der TU Berlin

Publisher: Universitätsbibliothek
Fasanenstr. 88 (im VOLKSWAGEN-Haus), D-10623 Berlin
Tel.: (030)314-76131; Fax.: (030)314-76133
E-Mail: publikationen@ub.tu-berlin.de
http://www.univerlag.tu-berlin.de

Acknowledgments

I would like to express my gratitude to Professor Dr. Peter Herrle[1], and Professor Claus Steffan[2], who guided me in the right direction throughout this research.

I have to thank my wife Simin Afshar Nia for her support during this work, my brother Kamiar Nasrollahi for his help in the research of heating and cooling systems and also my parents, Azizollah Nasrollahi and Sarvenaz Lalegani.

I also thank Drury Crawley (U.S. Department of Energy) and Linda Lawrie for preparing the required Weather Data and Andy Tindale (Director and founder of DesignBuilder Software Ltd) for his supporting during the use of DesignBuilder.

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Foreword

Mr. Nasrollahi has chosen a very challenging topic for his research: Climate and Energy Responsive Housing in Continental Climates, *The Suitability of Passive Houses for Iran's Dry and Cold Climate*: the Azarbaijan climate with warm summers and even very cold winters.

The challenge was to optimize houses for summer and winter periods to have as few heating and cooling demand as possible. To achieve reasonable results he used different simulation software tools such as DesignBuilder (EnergyPlus) and the "Passive House Planning Package". By running hundreds of various simulations he achieved, step by step, more efficient results through architectural form or passive means.

The strength of his work lies in the synoptic presentation of his results through very clear tables with 3 dimensional representations of housing types and their performance.

Mr. Nasrollahi has proven that it is possible to reduce heating and cooling energy consumption by more than 50% solely by architectural design. He showed as well, that the passive house-standard can be adapted very well in the Azarbaijan climate with even less thermal insulation than in Germany.

Finally he made economic analyses of energy efficiency through considering the various factors in the Iranian context.

His work is very precise and generates encouraging results. It is of high scientific value. His methods can be adapted to research in other climate zones.

I am happy that this work now has a continuation in the research project "Young Cities", where we at Berlin University of Technology study and develop energy- and climate optimized office buildings for the New Town of Hashtgerd in Iran.

Berlin, June 25th 2009

Prof. Claus Steffan

Foreword

The dissertation of Mr. Farshad Nasrollahi is one of a series of research studies currently produced at the Institute of Architecture on the issue of energy saving building design for the climatic conditions in Middle Eastern countries. Despite all efforts at the international level to curb the rapid depletion of oil resources, to slow down global warming, and the search for new environment-friendly technologies using renewable energy, politicians in oil-producing countries continue to rely on non-renewable energy sources and, moreover, have successfully blocked the development of innovative technologies by generously subsidizing energy prices. Only recently – caused by the slump in global economic development – critical voices on the large-scale waste of energy caused by inefficient heating and cooling systems seem to get more recognition.

Mr. Nasrollahi deserves the credit having ventured into the topic of energy saving building Iran while the vast majority of urban planners, architects, engineers in that country has only started to realize the significance of this issue for the future of the country. There is little public interest in energy saving solutions, and systematic research on this topic is still in an embryonic stage.

The concept of 'passive houses' as it has been developed over the past 20 years in Germany forms the basis of a thorough investigation as to whether at all and how concepts of building design and construction have an impact on energy consumption under the special climatic conditions of northern Iran. This topic goes well beyond a purely technocratic approach in that the solutions developed and discussed in Mr. Nasrollahi's dissertation are not just an application of new technical devices applied to existing building designs. His approach rather focuses on design factors, i.e. orientation, glazing, thermal mass, etc, which can be applied at comparatively low cost. Propositions are developed by using model calculations based on software that is readily available in the market.

The results are striking: The calculations indicate that the concept of 'passive houses' can effectively contribute to reducing the energy consumption for cooling as well as heating under conditions that are quite different from central Europe. Apart from the undoubted ecological benefits there are economic benefits already in the current policy framework which will sharply increase once the subsidies are reduced and incentive systems are established. Nasrollahi's work also delineates the fields where future research and testing is needed for a shift from an unsustainable waste of energy towards more coherent systems of design and construction.

It is hoped that that Mr. Nasrollahi's groundwork gets the wide recognition among practitioners and academics it deserves and that the results find their way into further research as well as the practice of engineers and architects throughout the country and eventually into decision and policy making circles.

Berlin, July 2009

Prof. Dr. Peter Herrle

Table of Contents

List of Tables

List of Figures

Abstract

Climate and Energy Responsive Housing in Continental Climates:

The Suitability of Passive Houses for Iran's Dry and Cold (Mountainous) Climate

In spite of worldwide climate change problems caused by fossil fuel use, energy consumption levels in Iran, while already high, continue to rise each year. Intensive fossil fuel use is also implicated in the high levels of air pollution found in some major cities, especially in Tehran. About 97% of the total energy consumption of Iran, and 98.8% of energy consumed by the building sector in this country is fossil fuel-derived, with residential and commercial buildings being responsible for over 40% of this amount. Iran's cold climatic region is extensive, and significant amounts of energy are consumed in these areas, especially for heating. However, due to the nature of its climatic conditions, this region has a high potential for energy saving in buildings. The introduction of energy efficient housing in this region would have a significant overall impact on national energy consumption levels.

The present research focuses on the cold climatic region in Iran, which is characterised by a continental climate, and it examines the city of Tabriz as a case study. The primary aim was to study the suitability of passive houses in Iran's cold climatic region and to identify those architectural factors most relevant for reducing building energy consumption. This work therefore attempts to answer the following two questions: firstly, are passive houses climatically, technologically and economically suitable for Iran's cold climatic region? And secondly, which architectural factors can most effectively decrease building energy consumption in this climate?

Because of present economic conditions in Iran, notably the subsidised cost of fossil fuels, energy savings in buildings through expensive conservation methods are not economically viable. Thus, there is little social interest in energy saving, especially where such measures increase building costs. Therefore this thesis argues that the use of cost-neutral building methods and cheaper architectural solutions is the most realistic and pragmatic approach. Architectural methods need not increase building costs, and savings are therefore achieved through improved design.

This work also briefly examines theoretical aspects of climate and of the effect of climatic factors on buildings, as well as examining the climatic response of various building types, passive solar heating systems and various passive and hybrid cooling methods. In addition, the work compares the energy situation, climate and residential architecture in Iran and Germany, and it introduces German concepts of energy efficient building and standards, with an emphasis on passive houses. The analysis section of treatise is organised as follows:

"**Comparison of Iran and Germany**" this first part of the analysis compares these two countries, with an emphasis on climatic conditions, and studies the feasibility of applying German passive house techniques and standards to Iran.

In order to provide accurate and detailed results, this research uses several different building energy software tools to evaluate climate data, building and system components and the economics of energy conservation. Dynamic simulation software tools (and hourly weather data) are also used to calculate the energy consumption of buildings. The energy software tools used in different parts of this analysis match the requirements for different stages of the research. They include EnergyPlus, DesignBuilder, Passive House Planning Package, Climate Consultant, GAEA and Economic Evaluation.

“Climate data analysis” analyses both the local climatic data and a psychrometric chart for Tabriz, to suggest the most appropriate passive design strategies for this city.

“Passive houses in Iran’s climate” uses the software “Passive House Planning Package”. It simulates passive houses in Iran’s cold climatic region to suggest suitable features for passive houses and the effect of architectural design on passive house energy requirements in this region. It indicates that not only are passive houses climatically suitable for winter conditions in this region, but that they are also more easily achievable, requiring less insulation. However, they do need additional cooling systems. “Simulation of subsoil heat exchanger” (using the GAEA software) shows the energy saving potential and economic efficiency of subsoil heat exchangers in Iranian passive houses.

To present a simulation of different architectural factors and building elements, **"Simulation of architectural elements"** uses DesignBuilder to search for the optimal case and the most appropriate application of each of these factors and elements under given conditions. An analysis of the simulations provided in this section shows the behaviour of energy efficiency in relation to different measures or quantities of various architectural factors and building elements. This section offers an explanation and rationalisation of the complex relationships between building energy use and architectural design.

“Simulation of Buildings with different Architectural Designs" uses DesignBuilder to simulate and compares the energy consumption of a typical building with some other newly designed buildings. The energy demand of the most efficient building is 63% less than the least efficient building available in similar control conditions, but with architectural design as the only variable. Therefore, the energy saving potential of architectural features in Iran’s cold climatic region is about 63%. However, by increasing the U-value of the thermal envelope this value increases (conversely, by reducing the U-value it decreases). The heating energy consumption of the most efficient building with only 12cm insulation is 12.13kWh/m²a, a value which reaches the Passive House Standard. This shows that architectural design profoundly affects heating, cooling and therefore the total energy consumption of buildings. Design impact varies according to specific climates; in climates which have a high temperature range, low relative humidity and high solar radiation (e.g. Iran´s cold climatic region), the architectural impact is very high. This section introduces those architectural factors which reduce the energy consumption of buildings in Iran’s cold climatic region.

There is a big difference in the construction costs (about 50%) for passive and non-passive houses in Iran. Nonetheless, based on the economic evaluation done in **“Economic Analysis”**, if the passive houses have an energy efficient architectural design, the use of these kinds of buildings is economically very viable when based on international energy costs. However, without governmental financial support, and in view of current subsidisation of fuel, investment for passive houses in Iran is economically not viable at present.

The section **“Mechanical Equipment”** outlines specifications for heating and cooling equipment which is climatically, economically and technologically appropriate for energy efficient and passive housing in Iran. Gas heat pumps can be integral to mechanical systems for heating and cooling both energy efficient houses and passive houses in Iran. Heater-cooler unit systems are also particularly suitable in this country.

In Iran’s cold climatic region, the energy consumption of a well-insulated, suitably-designed building is only 8.3% of an uninsulated normal house, so the potential for energy saving in buildings is very high. Therefore, to solve this problem the present research strongly suggests using both architectural techniques and insulation materials.

German Abstract

Klima- und Energiegerechter Wohnungsbau im kontinentalen Klima: Die Eignung von Passivhäusern für das kalt-trockene Gebirgigsklima im Iran

Trotz der weltweit steigenden Energiepreise und der Umweltprobleme im Zusammenhang mit dem fossilen Energieverbrauch, steigt der Energiebedarf im Iran fortwährend, basierend auf einem bereits hohen Verbrauchsniveau. Der hohe Energieverbrauch führt in einigen großen Städten auch zu einer starken Luftverschmutzung, insbesondere in Teheran. Über 97 Prozent des gesamten Energieverbrauchs und 98,8 Prozent des Energiebedarfs in Gebäuden werden von Erdöl und Erdgas abgedeckt. Der Energieverbrauch in Wohn- und Geschäftsgebäuden im Iran beträgt mehr als 40 Prozent des gesamten Energieverbrauchs. In den kalten Regionen, die einen umfassenden Teil der iranischen Landmasse ausmachen, ist der hohe Energieverbrauch insbesondere auf den Betrieb von Heizungsanlagen zurückzuführen. Aufgrund der besonderen klimatischen Bedingungen haben diese Regionen ein hohes Energieeinsparpotenzial im Gebäudesektor. Die Einführung von energieeffizienten Häusern in diesen Regionen hätte einen wesentlichen Einfluss auf den Gesamtenergieverbrauch des Landes. Die vorliegende Arbeit konzentriert sich auf die kalte Klimazone des Irans mit einem kontinentalen Klima und auf die Stadt Tabriz als Fallstudie. Die folgenden Fragen sind Forschungsfragen dieser Arbeit: (1) Sind Passivhäuser klimatisch, technologisch und wirtschaftlich für kalte Region des Irans geeignet? Und (2) Welche architektonischen Faktoren können den Energieverbrauch von Gebäuden in diesem Klima senken?

Aufgrund der wirtschaftlichen Bedingungen im Iran und insbesondere aufgrund der subventionierten niedrigen Energiekosten sind Maßnahmen zur Energieeinsparung in Gebäuden unter Hinzufügung kostenintensiver Verfahren heute nicht wirtschaftlich. Es gibt somit kein wirtschaftliches Interesse am Energiesparen, insbesondere nicht durch Maßnahmen, welche die Baukosten wesentlich steigern könnten. Vor diesem Hintergrund wurde in dieser Arbeit insbesondere die Verwendung kostenneutraler Methoden sowie kostengünstige Energiesparmaßnahmen, insbesondere unter Anwen- dung architektonischer Maßnahmen untersucht. Architektonische Maßnahmen erhöhen nur bedingt die Baukosten und sind nur durch eine angemessene Gestaltung im Bereich des Entwurfs erreichbar.

Der theoretischen Teil der vorliegenden Arbeit reflektiert den Einfluss des Klimas auf den Energieverbrauch und den Komfort in Gebäuden. Darüber hinaus wurde der Stand der Technik zu den Themengebieten klimagerechte Gebäude, passive solare Heizsysteme und zu verschiedenen passiven und hybriden Kühlmethoden, die in Gebäuden anwendbar sind aufgeführt. Anschließend wird die Energiesituation, das Klima und die Architektur im Bereich des Wohnungsbau im Iran und in Deutschland aufgezeigt und verglichen sowie deutsche Baustandards für den energieeffizienten Wohnungsbaus mit dem Schwerpunkt Passivhäuser vorgestellt.

„Vergleich Iran - Deutschland“ überschreibt den ersten Schritt der Analyse, vergleicht diese beiden Länder mit Schwerpunkt auf klimatische Bedingungen und untersucht die Durchführbarkeit der Anwendung Deutscher Passivhauskonzepte im Iran.

Als Untersuchungsmethode für genaue und detaillierte Aussagen nutzt die vorliegende Forschung verschiedene Softwareprogramme zur Auswertung von Klimadaten, Bau- und Systemkomponenten sowie für die Ermittlung der Wirtschaftlichkeit in Bezug auf die unterschiedlichen Maßnahmen des Energiesparens. Programme zur dynamischen Simulation von Gebäuden unter Verwendung stündlicher Wetterdaten werden darüber hinaus zur genauen Berechnung des Energieverbrauch der untersuchten Gebäudentypologien verwendet. In den verschiedenen Abschnitten der Untersuchung wurden hierfür je nach Anforderung die Programme „EnergyPlus“, „DesignBuilder“, „Climate Consultant“, „Passivhaus Projektierungs Paket (PHPP)“, „GAEA“ „ÖKO-RAT“ verwendet.

Im Abschnitt **„Klimadaten Analyse“** wurden sowohl die lokalen Klimadaten wie auch ein psychrometrisches Diagramm verwendet, um die am besten geeigneten passiven Entwurfstrategien für die Stadt Tabriz zu finden.

Der Abschnitt **„Passivhäuser für Klima des Irans“** verwendet die Software PHPP und simuliert

Passivhäuser in der kalten Klimazone des Irans um die passenden Passivhäuser vorzustellen und die Wirkung des architektonischen Entwurfs auf den Energieverbrauch in dieser Region zu untersuchen. Es deutet darauf hin, dass nicht nur Passivhäuser für die winterlichen klimatischen Bedingungen dieser Region geeignet sind, sondern dass die Einsparziele im Vergleich zu den Deutschen Vorbildern auch leichter erreichbar sind und insbesondere mit weniger Wärmedämmung realisiert werden können. Allerdings werden zusätzliche Maßnahmen zur Gebäudekühlung benötigt. Im Abschnitt „Simulation von Erdwärmetauschern" wurden mit Hilfe der Software „GAEA" die Energieeinsparpotenziale und die Wirtschaftlichkeit von Erdwärmetauschern innerhalb von Passivhäusern im Iran aufgezeigt.

Im Abschnitt **„Simulation der architektonischen Elemente"** wird das Programm „DesignBuilder" für die Simulation verschiedener architektonischer Faktoren und Bauelemente verwendet, um die am besten geeigneten architektonischen Faktoren und Bauelemte und deren optimale Konfiguration bei den jeweils gegebenen Rahmenbedingungen zu ermitteln. Die Analyse der Simulationen in diesem Abschnitt zeigt das Verhalten der Energieeffizienz in Bezug auf die jeweils verwendeten, unterschiedlichen baulichen Maßnahmen und Entwurfsvarianten. Es zeigt auch, wie der Energieverbrauch in Bezug auf die verschiedenen architektonischen Faktoren jeweils erhöht oder verringert wird. Dieser Abschnitt zielt darauf ab, ein tiefes Verständnis und Gefühl des komplexen Verhaltens von Gebäudeenergieverbrauch in Bezug auf die architektonische Gestaltung zu erhalten.

Im Abschnitt **„Simulation von Gebäuden mit unterschiedlichem architektonischen Entwurf"** wird bei vergleichnder Durchführung von Gebäudesimulationen unter Verwendung des Programms „DesignBuilder" der Energieverbrauch eines typischen Gebäudes der Region mit einigen anderen prototypisch neu gestalteten Gebäuden verglichen. Der Energiebedarf der am effizientesten gestalteten Gebäude ist 63% niedriger als die aufgeführten Bestandsgebäude bei ausschließlicher Veränderung der architektonischen Gestaltung aber unter sonst vergleichbaren Bedingungen. Aufgrund dieser Untersuchung kann das Energieeinsparpotenzial der architektonischen Maßnahmen für die kalte Klimazone des Irans auf 63% beziffert werden. Durch die Erhöhung Erhöhung des U-Wertes kann dieser Wert noch deutlich gesteigert werden. Der Heizenergieverbrauch der effizientesten Gebäude konnte mit nur 11.8cm Dämmstoffen auf den Fassaden- und Dachflächen so auf 12.13kWh/m²*a gesenkt werden. Ein solcher Verbrauchswert erfüllt die Anforderungen des Passivhausstandards. Es beweist, dass architektonische Gestaltung den Heiz-, Kühl- und Gesamtenergieverbrauch von Gebäuden stark beeinflusst. Die Auswirkungen der Gestaltung ändern sich je nach dem spezifischen Klima. In Regionen mit einer hohen tageszeitlichen Temperaturamplitude, mit einer niedrigen relativen Luftfeuchtigkeit, mit hoher Sonneneinstrahlung und geringem Bewölkungsindex, wie sie in der kalten Klimazone des Irans vorliegt sind die Einflüsse sehr hoch. In diesem Abschnitt wurden die architekton- ischen Faktoren, die den Energieverbrauch von Gebäuden senken könnten genauer vorgestellt.

Es gibt einen großen Unterschied bei den Baukosten (ca. 50%) zwischen den Passivhäusern und der konventionellen Bauweise im Iran. Die Wirtschaftlichkeitsberechnung im Abschnitt **„ökonomische Bewertung"** zeigt aber, dass bei Annahme von Weltmarktpreisen für die zugrundegelegten Energiekosten die Verwendung von Passivhäusern mit energieeffizienter Architektur eindeutig wirtschaftlich ist. Ohne eine staatliche finanzielle Unterstützung der spezifischen Baumaßnahmen und unter den gegenwärtig subventionierten und entsprechend niedrigen Energiekosten sind Investitionen für Passivhäuser im Iran heute nicht wirtschaftlich.

Der Abschnitt **„Heiz- und Kühlanlage"** schlägt klimatisch, wirtschaftlich und technologisch geeignete Heiz- und Kühlanlagen für energieeffiziente Gebäude im Iran vor. Gaswärmepumpen sind unter bestimmten Vorraussetzungen für Heiz- und Kühlanlagen von Energieeffizienten Gebäuden im Iran geeignet. Kombinierte Heizungs- und Kühlaggregate (Heater-Cooler-Systems) sind besonders ideal für diese Gebäude.

In der kalten Klimaregion des Irans liegt der Energieverbrauch eines wie empfohlen gut isolierten und gut konzipierten Gebäudes bei nur 8,3% eines konventionellen, nicht isolierten Objektes und weißt für diese Region somit ein außergewöhnlich hohes Einsparpotenzial auf. Als Kernaussage der Arbeit wird für diese Region die Verwendung der architektonischen Optimierung und der erhöhten Nutzung von Dämmstoffen in Kombination mit einer geänderten Förderstrategie besonders empfohlen.

Introduction

Research Problem

Naturally occurring fossil fuel resources are finite and the increasing global population is faced with a shortage of energy. Fossil energy consumption also leads to many problems such as the emission of greenhouse gases which cause environmental pollution and climate change, effectively decreasing the quality of human life. This is a serious and irreversible global threat. Moreover, the price of fossil energy is high and continually increasing. Worldwide energy consumption must therefore be slowed.

Iran's energy consumption, while already high, is increasing at a rate of 6[1]-7%[2] per annum (Based on data from National Iranian Oil Company 2004, pp.233-234 and Iran Ministry of Energy 2006b). Because of the country's oil resources, fossil fuels are used without regard to their importance. Approximately 97% of Iran's total energy consumption (and 98.8% for its buildings) is supplied from oil products and natural gas (Based on data from Energy Information Administration 2008a, p.1 and Iran Ministry of Energy 2006, p. 57).

If trends continue, Iran's energy supply (the country's most valuable source of foreign exchange revenue) will soon be depleted. The majority of its oil resources are also in the second half of their life span and other resources are expensive and inefficient (Omidvar 16.02.2006)[3]. It is possible, however; for Iran to achieve a high reduction in its energy consumption.

Alternative energy resources such as renewable energies are not practically nor widely used in Iran, only experimentally in different fields. Iran is, however, spreading the use of such renewable energies as wind and especially solar energy. A small-scale conversion is also being made to nuclear energy for the production of electricity in an effort to counter this increased consumption.

On the other hand some of Iran's larger cities, particularly Tehran, produce high levels of air pollution, far exceeding the standards set by the WHO[4] and posing serious health problems (Sarbib et al. 2001b, p.18). The preservation of energy and reduction of energy consumption are, therefore, very important for Iran.

Energy consumption in buildings (via heating, cooling and lighting) is a significant portion of worldwide energy consumption. Much of this energy is consumed through the heating of buildings, especially in cold climates.

Residential and commercial buildings are responsible for over 40% of Iran's high energy consumption. A reduction in energy consumption and the introduc-

1 - Between 2000-01 and 2003-04.
2 - Between 2002-03 and 2004-05.
3 - BBC.com.
4 - World Health Organization.

tion of energy efficient houses would, therefore, have a significant impact on the country's overall consumption.

State of Knowledge

The attention to climatic design refer to late forties with the attempt of James Marsten Fich and then since oil crises of 1973 energy saving in buildings became more important and afterwards there were built different energy efficient and climate responsive buildings. The science of climate responsive buildings developed from the extensive theoretical and practical research carried out during this period.

With energy saving playing a prominent role in modern day building design, there exist many examples and prototypes for energy efficient design such as Zero-Energy, Zero-Heating and Zero-Carbon, Positive Energy and autonomous buildings. These are built all over the world, meeting a variety of standards. Some of the key pioneer standards are stated below:

Germany: Low energy house, Passive House, Autonomous House Standard

Canada: Canada R-2000 Standard, Canada Advanced House Standard (Toronto), Healthy Houses includes environmental standards other than energy, Autonomous House Standard

Sweden: Sweden 1989 Building Code

Norway: Norway 1995 Building Code

Switzerland: MINERGIE Program (Zurich Canton) Building Code, Passive House, Autonomous House Standard

Austria: Passive House

Research Questions

The following questions make the backbone of the present research. As well, they intend to direct the mind the reader to share in the possible solutions.

1. Which kind of buildings are climate and energy responsive for the cold climatic region of Iran?
2. Are passive houses climatically, technologically and economically suitable for Iran's cold climatic region?
3. Is it possible to reduce the energy consumption of individual low-rise houses (1 to 3-story houses) through architectural design in Tabriz, in the very cold climatic region of Iran?
4. Which architectural factors can decrease the energy consumption of buildings in this climate?

Research Area

The present research is to focus on Iran. It should be noted that the country contains several different climatic regions. As much of Iran falls within the cold region, a large portion of the country's total fossil energy is consumed in buildings of this area, especially for heating. The research area is the cold climatic region of Iran, which from a geographical viewpoint is a mountainous region. According to Olgyay's bioclimatic chart, mountainous regions experience very cold winters and warm, dry summers.

Climatic conditions vary between cities due to differences in latitude, elevation, distance from the sea, direction of seasonal winds, precipitation and humidity (Ghobadian 2003, p.1). For this reason, it is necessary to elect a smaller part of this region as the case study. One of Iran's larger cities (major city of Provinces) will, therefore, be selected. This selection will be based on fuel consumption, heating degree day and population.

For selecting this city, the amount of fuel consumption, heating degree day and population of these cities are compared. Although Tabriz has the fifth largest annual heating degree day of the cold cities, it has the highest fuel consumption and population (city and suburbs). Tabriz, the major city of the province of East Azarbayejan, has therefore been selected as the case study.

Methodology and Structure

This work primarily aims to study the suitability of passive houses for Iran's cold climatic region and identify which architectural factors reduce the energy consumption of its buildings. Iran´s cold climatic region is large in area and its buildings have high energy requirements, particularly for heating. There is, however, high potential for passive heating and cooling due to such climatic conditions as high solar radiation, low relative humidity and high temperature range in the region and energy savings can be made through these passive means.

Throughout this research the architectural design and architectural factors are to be treated as independent variables, and annual energy consumption of buildings (kWh/m^2a) as dependent. Other factors such as climate and internal gains (through occupants, household appliances, and lighting) will be control variables. These control variables must remain stable in the simulation and analysis so that they do not affect the dependent variable (energy consumption). While the dependent variable remains constant, the independent variables (architectural factors) vary throughout the work. Some of these include orientation, elongation, number of stories, area of south-facing windows, and operation of adjustable shading devices. The dependent variable (energy consumption) has a numerical quantity and is calculated via energy simulation. A comparison of the energy consumption of buildings in the same conditions is then used in order to find the effect of the independent variables on the dependent variable.

Building Energy Software Tools are computer programs for the analysis and evaluation of climate data, building energy consumption and performance, building and system components, and economic evaluation of energy saving. They lead to detailed and accurate results. A suitable software tool has therefore been selected to match the requirements of each stage of research (i.e. evaluation, simulation and analysis).

Building energy simulation is a powerful analytical method for building energy research and evaluation of architectural design (Hensen et al. 1993, pp.17-23, Seth 1989, pp.240-247) and it is also a time saving device. It aims to imitate the real physical conditions in a building by creating a mathematical model that represents all energy flow paths in a building as well as their interactions (Rizos 2007, p.16).

Simulation with properly developed dynamic simulation software tools and hourly weather data (to define external conditions during simulations) is therefore used in this research to accurately calculate energy consumption. It also allows an estimation of peak design thermal loads of buildings and a detailed analysis of their thermal behaviour. Four such software tools have been selected to suit the requirements of present work.

EnergyPlus is one of the most popular and effective dynamic energy simulation programs, however it reads and writes output as text files. DesignBuilder, one of 'EnergyPlus' comprehensive graphical user interfaces, is therefore primarily (but not exclusively) used throughout this research due to its graphical presentation of results in the energy modelling of buildings. It has many capabilities needed for this work.

The "Passive House Planning Package" (Passiv-Haus-ProjektierungsPaket), another stationary modelling program, is especially designed for passive houses. It is able to model all components used in passive houses. Therefore, this program is used in the section of present research that studies passive houses in Iran's cold climatic region. The energy consumption of buildings in the simulation of passive houses is referred to as heating demand[1] and is calculated using the "Passive House Planning Package". The results of this part of the analysis only concern the reduction of heating energy consumption.

Elsewhere in this treatise, the energy consumption of buildings relates to both heating and cooling and is mostly calculated through dynamic modelling with DesignBuilder. In DesignBuilder's output data, the heating energy consumption is referred to as 'Boiler' and the cooling energy as 'Chiller'. The Boiler is defined as "total boiler fuel consumption" and the Chiller as "total chiller fuel consumption" (DesignBuilder Software Ltd. 2008, p.310). The results of the majority of the research and final results concern both the reduction of heating and cooling energy consumption of buildings.

External validity of this research is to save energy without increasing the building costs in Iran's cold climatic region and to ultimately decrease the energy consumption of Iran. This has several environmental and economical advantages. Another aspect of external validity of present research is to reduce the cost of passive houses (by the use of architectural energy saving principles at the

1 - Called Heizwärmebedarf in the PHPP program.

design level), making passive houses economically viable and thus more popular.

Three different building simulation and analysis methods are used to find which architectural factors reduce the energy consumption of buildings, and the optimal case for each building component. These methods are separately stated in the introduction of each of these parts. This work is divided into an introduction and five subsequent chapters.

Introduction includes problem statement, research questions, research area and methodology.

Chapter one (Climate and architecture) concisely introduces the worldwide energy situation and different climate scales, discusses the effect of climatic factors on architecture from the viewpoint of energy (consumption) and indoor comfort conditions, climate responsive buildings (and their characteristics) and states passive heating and cooling strategies suitable for cold climates.

Chapter two (Iran) studies different climatic zones of Iran, introduces the research area and buildings in Iran, and briefly surveys the traditional buildings of the research area.

Chapter three (Germany) introduces Germany's climate and energy situation and studies several German energy efficient buildings with an emphasis on passive houses.

Chapter four (analysis) presents accurate results from various stationary and dynamic simulation and analysis software tools. This chapter contains the following parts:

1. **"Comparison of Iran and Germany"** compares Iran and Germany with an emphasis on climatic conditions in order to study the feasibility of applying German passive houses to Iran.
2. **"Climate data analysis"** analyses the climatic data and psychrometric chart for Tabriz to find the most appropriate passive design strategies for this city.
3. **"Passive houses in Iran's climate"** simulates passive houses in Iran's cold climatic region to find the passive house characteristics in this region.
4. **"Simulation of architectural elements"** presents the simulation of different architectural elements in search of the optimal case for each of these elements under given conditions for other elements.
5. **"Simulation of Buildings with different Architectural Designs"** deals with the simulation and comparison of energy consumption of one typical and 28 other newly designed buildings to find which architectural factors reduce the energy consumption of buildings.
6. **"Economic Analysis"** deals with the economic analysis of passive houses by considering several parameters (including initial investment, energy saving, energy costs, operation costs, period of time (life span), interest rate, general and energy inflation rate) in order to evaluate the cost effectiveness of passive houses in Iran.

7. **“Mechanical Equipment”** deals with the economically and technologically suitable heating and cooling equipment for energy efficient and passive houses in Iran.

Chapter five (Conclusion and recommendation) discusses the results of present research.

Chapter One: Climate and Architecture

Introduction

Various natural and built-up elements such as topography, altitude, water bodies, land cover and constructed surroundings modify the characteristics of a macroclimate and change it to a microclimate. The microclimate of the area in which a building is constructed affects the indoor climate of a closed or architectural space. Buildings provide essential protection against the outdoor climate. Furthermore, they create an artificial indoor climate based on the given microclimate of the surroundings. Architectural elements forming the thermal envelope such as walls, windows, roofs and floors separate the microclimate and indoor climate and thus significantly influence the indoor climate.

Buildings are considered as “climate modifiers” which could take advantage of local weather to enhance their architectural integrity and environmental quality (Hui and Tsang 2005, p.2).

Architectural design and structural elements must produce an indoor climate that conforms better to the human comfort zone in both winter and summer. The spontaneous indoor climate often does not conform to the required indoor thermal comfort conditions[1], thus making additional heating or cooling necessary. HVAC systems are used to change an indoor climate to comfortable thermal conditions for occupants. As this process requires primary energy, a smaller difference between the indoor climate and comfortable conditions relates to lower energy consumption.

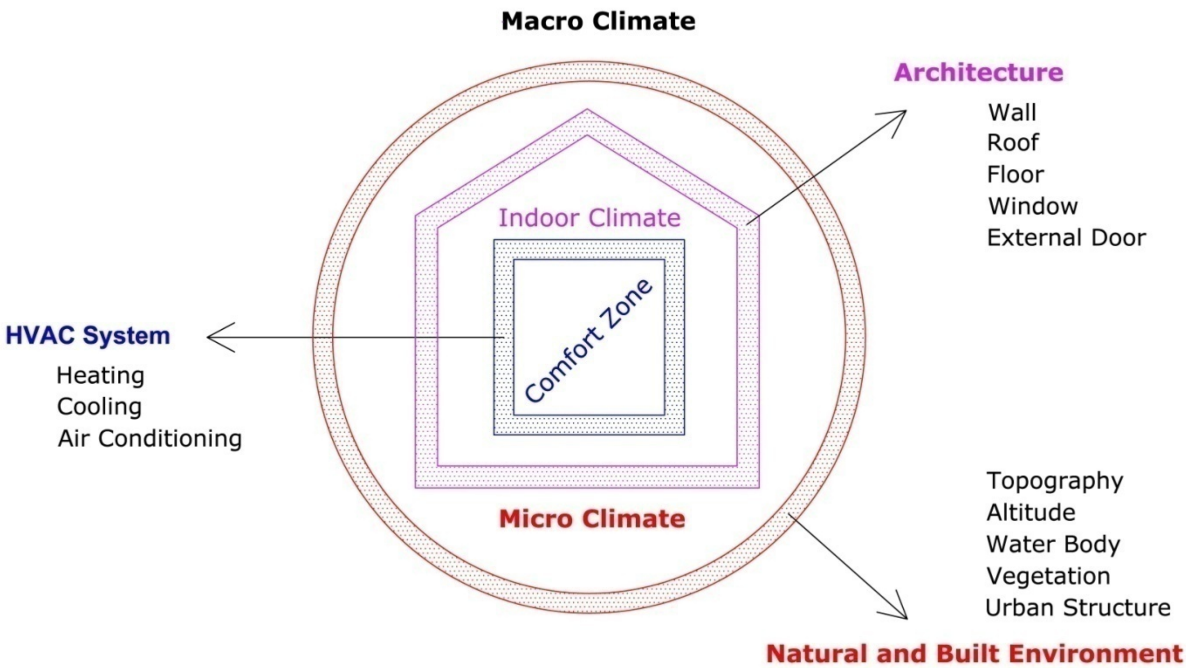


Figure 1: Relationship between Climate and Architecture

[1] - This varies based on climate and architectural design.

There are various climate classifications and climatic zones. The climatic zones are often classified based on air temperature and humidity. Some common climatic zones that are classified based on these two climatic factors are:

- cold
- temperate and dry
- temperate and humid
- warm and dry, and
- warm and humid.

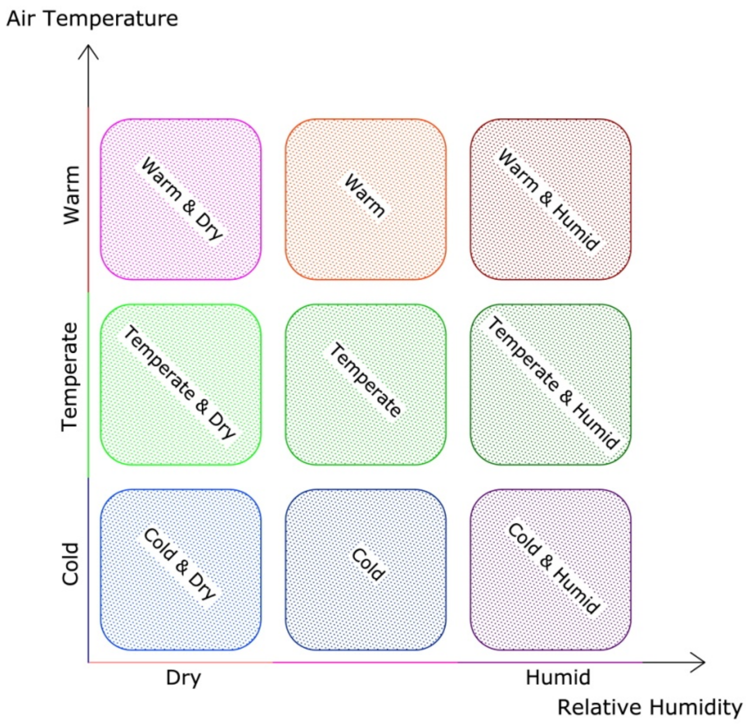


Figure 2: Different climate zones based on temperature and relative humidity

Air temperature, solar radiation, humidity and wind are the main climatic factors relating to construction. The following table shows the characteristics of these climatic factors in the main climate zones:

Table 1: Characteristics of climatic factors in different climatic zones

	Cold	Temperate & dry	Temperate & humid	Warm & dry	Warm & humid
Air Temperature	Low	Medium	Medium	High	High
Air Humidity	Low	Low	High	Low	High
Solar radiation			Low	High	Low
Precipitation	--	--	--	Low	--
Wind	--	--	--	--	--

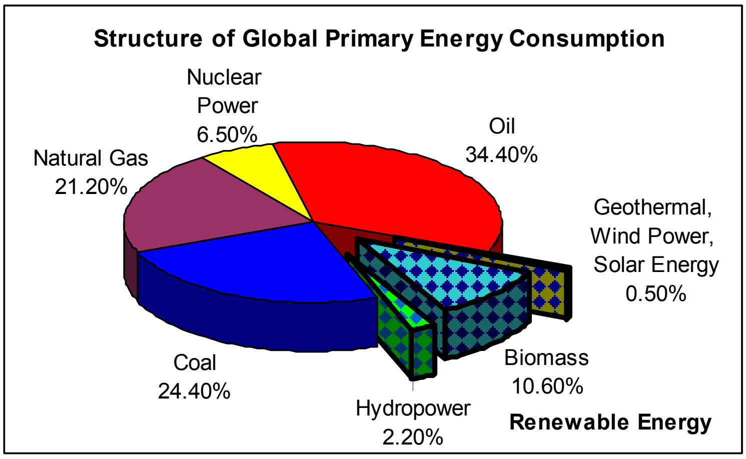
Wind and especially solar radiation are often used for design objectives in all climate zones during both overheating and underheating periods.

The general design objectives for each climatic region are:

- Cold: Maximize the warming effects of solar radiation. Reduce the impact of winter wind.
- Temperate: Maximize warming effects of the sun in winter, maximize shading in summer, and reduce the impact of winter wind while allowing air circulation in summer.
- Hot-Arid: Maximize shade and minimize hot, dust-laden winds.
- Hot-Humid: Maximize shade and wind (Brown and Dekay 2001, p.88).

Energy

Only 13.3% of global primary energy consumption relates to renewable energy sources and thus current global primary energy consumption is still dominated by fossil energy carriers. Oil secures a share of more than one third (34.40%) of the global energy consumption. The second largest energy carrier consumed as primary energy is coal with 24.4%, followed by natural gas with 21.2%. Among the renewable energies, biomass has the greatest energy consumption at 79.7%, followed by hydropower at 16.5% and geothermal, wind power, and solar energy combined at only 3.8% (BMU 2006, p.68).



Source: Based on data from BMU 2006, p.51

Climate

The world's prevailing climates vary greatly, ranging from the polar extreme to tropical climates. These are primarily influenced by the sun's energy heating the land and water masses (Gut and Ackerknecht 1993, p.15).

Climates can be studied at several scales, namely macro-climate, meso-climate, local-climate and micro-climate. "These terms differ on the basis of spatial scale" (Tarara 2005, p.9). According to their classical definitions, there is some overlap between these climate scales. The following graph shows the approximate spatial distance of each:

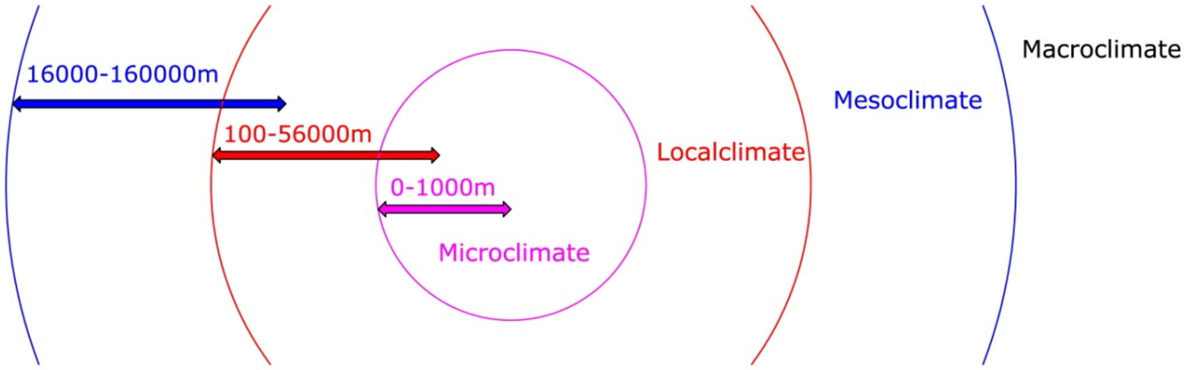


Figure 3: Spatial distance of different climate scales, Source: based on data from Stuller 1995

Of these climate scales, microclimate and macroclimate are most often considered for climatic design (relating to climate and architecture).

Macro Climate

Macroclimate is the general climate or average weather of an area ranging in scale from regional to global (Tarara 2005, p.9). It can almost encompass a continent (Stuller 1995).

"Macroclimate accounts for the largest share of systematic environmental variation at the macroscale or ecoregional level" (Robert and Bailey 2004, p.3). The general term 'climate' implies macroclimate unless otherwise specified.

Meso Climate

Mesoclimate ranges in scale from an extensive yard area to a region (Tarara 2005, p.9). The "meso" scale (and the scales obviously overlap) ranges from 10 miles to hundreds of miles (Stuller 1995). Some meteorology/climatology texts define the mesoscale as ranging from one mile to 50 or 100 miles, including such weather phenomena as tornadoes, thunderstorms, and valley winds (Tarara 2005, p.9).

Local Climate

There are distinct anomalies within what atmospheric scientists call "local" scale climate, which ranges from about 100 yards to as much as 35 miles (Stuller 1995).

Micro Climate

"Local conditions, however, may also differ substantially from the prevailing climate of a region, depending on the topography, the altitude and the surroundings, which may be either natural or built by humans" (Gut and Ackerknecht 1993, p.20).

Every elevation difference, characteristic of land cover, and water surface induces variations in a local climate. These effects within the large scale "macro-climate" form small-scale "micro-climates" (Olgyay 1963, p.44).

Microclimates, however, are manifestations of prevailing atmospheric influences in areas not much larger than a square mile, and even in spaces as small as a half-inch (Stuller 1995). But according to Julie Tarara (2005, p.10), microclimate extends from the scale of inches to the scale of a few hundred yards.

On a large scale, topography, solar radiation, and wind combine to produce microclimates that accentuate certain characteristics of the area's macroclimate (Brown and Dekay 2001, p.86).

The orientation and layout of streets has a significant effect on the microclimate surrounding buildings and the solar and wind access for use in buildings (Brown and Dekay 2001, p.102). The local urban microclimate is modified by the "structure" of the city, and particularly that of the neighbourhood surrounding a given building. The urban microclimatic conditions thus form the immediate environment of the individual buildings. This modified climate directly affects the indoor comfort conditions and the inhabitants' energy use for heating and/or air conditioning (Givoni 1998, p.xii preface).

Microclimate can also be improved by planting vegetation and inserting pools and water bodies around the building and even in its courtyard.

Climatic Factors

The main climatic factors relating to construction are those which affect human comfort. These elements can be categorised as:

- Air temperature, its extremes, and diurnal and seasonal temperature differences
- Humidity and precipitation
- Incoming and outgoing radiation and the influence of sky conditions
- Air movement and wind (Olgyay 1963, p.32, Gut and Ackerknecht 1993, p.15).

The climate of a region is assessed according to the long-term averages of each of the climatic factors, however, as conditions may vary greatly from day to day and year to year, deviations from the average should be taken into account for a more realistic view when dealing with climatic problems. For many applications, the extreme conditions and their expected frequency may be of greater importance than the average conditions (Givoni 1969, p.1). The climatic factors relevant to buildings are stated below.

Air Temperature

Daily and yearly variations in atmospheric temperature are dependent on incoming solar energy. Hence, both air temperature and radiation have to be considered for design purposes (Olgyay 1963, p.32). “The air layer in direct contact with the warm ground is heated by conduction; this heat is transferred to the upper layers mainly by convection and with the turbulence and eddies in the air. Currents and winds bring large masses of air into contact with the earth's surface, to be warmed in this way” (Givoni 1969, p.6).

The variation of diurnal temperature depends on the state of the sky. On clear days a large amount of incoming radiation and a free path for outgoing radiation produce a wide daily temperature range. During overcast days the variation is less. On a seasonal basis the same holds true: clear days in summer are warmer because more solar energy is received, but a clear day in winter is usually cooler than a cloudy one because in a longer period of nocturnal outgoing radiation heat escapes more easily through clear atmosphere (Olgyay 1963, p.32). The air temperature also determines the convective heat exchange between the skin and the ambient air (Givoni 1998, p.14).

Wind

The wind distribution and characteristics over a region are determined by several global and local factors. The principal determinants are the seasonal global distribution of air pressure, the rotation of the earth, the daily variations in heating and cooling of land and sea, and the topography of the given region and its surroundings (Givoni 1969, p.8).

The wind’s quality is dependent on its origin. It can be dry or humid, clean, dusty or sandy, hotter or cooler than the prevailing temperature, constant or irregular. Accordingly, wind can either be utilised for improvements to the indoor climate of buildings or measures must be taken to protect against it (Gut and Ackerknecht 1993, p.34).

Solar Radiation

Solar radiation is an electromagnetic radiation emitted from the sun (Givoni 1969, p.1). It can be used for heating buildings during cold periods.

Components of Solar Radiation

“Any part of a building that is exposed to the sun will be heated by solar radiation, which may arrive at the building’s surface in three ways – as direct, diffuse and reflected radiation” (Watson 1985, p.14). Direct beam radiation comes from the sun, diffuse radiation from the sky, and reflected, direct, and diffuse radiation from the ground and other external surfaces (Yannas 1994, p.30). The sum of direct and diffuse solar irradiation on a surface is known as the global irradiance (Goulding et al. 1992, p.20).

The solar spectrum is broadly divided into three regions: the ultra-violet, the visible and the infra-red (Givoni 1969, pp.1-2) . The solar radiation reaching the earth's surface has wave lengths in the range of 0.25 microns to 4 microns (Goulding et al. 1992, p.54). Visible and infrared light both have a heating effect on man but ultraviolet light has a biologic effect, and between 0.288 and 0.313 microns (which is the effective range of ultraviolet light) causes sunburn. When the sun's rays strike glass, much of the short wave and visible radiation is transmitted but the radiation that affects the skin is blocked (Kasmaei 2004, p.17). So any solar radiation penetrating through glass facades has no harmful effect on human skin.

Amount of Solar Radiation

The amount of solar energy reaching the earth's surface is related to:

1. The distance between the earth and the sun.
2. The distance the sun's rays travel through the atmosphere.
3. The angle at which these rays strike an intercepting surface.
4. The time the sun is above the horizon.
5. Atmospheric conditions of the site (Johnson 1981, p.18).

From a geographical viewpoint, the amount of solar radiation reaching the earth's surface depends on: (1) latitude, (2) atmospheric conditions, and (3) elevation.

Also, at a particular site two factors have a major influence on solar energy: (1) turbidity of the atmosphere, and (2) geometric obstructions consisting of topography, vegetation, and buildings (Goulding et al. 1992, pp.30-31).

When the striking solar beams are perpendicular to a surface, this surface can absorb the greatest amount of energy.

The intensity of solar radiation received on any surface can be calculated using the cosine law:

$I_s = I_n \cos \Theta$

Where:

I_s: Intensity of radiation falling on surface

I_n: Intensity of radiation normal to the solar beam

Θ: Angle between the solar beam and a line normal to the surface

The angle of incidence (Θ) is found by the spherical cosine equation, which states:

$\cos \Theta = \cos \beta \cos (\text{Ø}-\psi)$

Where:

β: Solar altitude

Ø: Solar azimuth angle, measured clockwise in degrees from north ψ: Wall orientation (wall azimuth) angle, measured clockwise in degrees from north (Watson and Labs 1983, pp.38-39).

Cloudiness Index

To calculate the atmosphere's clarity, a coefficient called the cloudiness index (K) is used. This is the ratio of solar energy reaching a surface on the ground (H) to solar energy reaching the same surface, in the same latitude and longitude, and the same time just out of the earth's atmosphere (Ho).

K= H / H o (Williams 1983, p.187)

This coefficient alters between locations and can be calculated in various ways.

Precipitation

Large-scale cloud formation and precipitation are the result of adiabatic cooling of large air masses, and are affected greatly by the vertical stability of the air (Givoni 1969, p.16). As Gut and Ackerknecht (1993, p.36) explain, Due to the topography, distribution of water bodies and winds, the types and quantity of precipitation vary strongly. The differences in precipitation patterns are reflected in construction details and building types, at least traditionally.

Atmospheric Humidity

The term atmospheric humidity refers to the water vapour content of the atmosphere. Water vapour enters the air by evaporation, primarily from ocean surfaces but also moist surfaces, vegetation, and small water bodies. The vapour is carried and distributed over the earth's surface by the wind. "The air's capacity for water vapour increases progressively with its temperature, which is the principal determining factor" (Givoni 1969, p.13). The content of the atmospheric humidity can be expressed in several terms, such as the absolute humidity, vapour pressure, specific humidity, and relative humidity. Relative humidity is the ratio of actual absolute humidity to the air's maximum moisture capacity at its current temperature. This is expressed as a percentage of the absolute saturation humidity.

Both the vapour pressure and relative humidity vary greatly with place and time. "The relative humidity may undergo wide variations even when the vapour pressure remains nearly constant. These are caused by the diurnal and annual changes in air temperature, which determine the potential moisture capacity of the air. Large diurnal variations in relative humidity are found mainly in the continental regions experiencing large diurnal temperature ranges" (Givoni 1969, p.15).

Indoor Climate

One of the main functions of the buildings is to protect the inhabitants from outdoor climatic conditions which are often harsh and hostile. The building must provide an environment that does not harm the health and of the inhabitants. Moreover, it should provide living and working conditions which are comfortable (Gut and Ackerknecht 1993, p.39).

A building's indoor climate differs from its surrounding outdoor climate. Indoor temperatures are usually different from the outdoor temperature, even when the buildings are not mechanically heated or cooled. The actual relationship between the indoor and outdoor climates depends to a great extent on the architectural and structural design of the buildings and thus the indoor climate can be controlled by building design to accommodate human comfort needs (Givoni 1998, p.xii Preface).

Comfort Zone

Man strives for the point at which minimum expenditure of energy is needed to adjust himself to his environment. Conditions under which he succeeds in doing so can be defined as the "comfort zone" wherein most of his energy is freed for productivity (Olgyay 1963, pp.14-15).

"Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. Because there are large variations, both physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space" (ANSI and ASHRAE 2004, p.4)[1]. Thermal comfort is affected by independent environmental variables and independent personal variables (ASHRAE 2001, pp.8.12-13). The environmental factors are temperature, thermal radiation, humidity, and air speed and the personal factors are activity level and clothing (Ubbelohde et al. 2003, p.3). Environmental factors affect the human body simultaneously, and the influence of any one depends on the levels of the other factors (Givoni 1969, p.68).

The following six primary factors define conditions for thermal comfort:

1. Air temperature
2. Radiant temperature
3. Air speed
4. Humidity (Gut and Ackerknecht 1993, p.42, Lechner 1991, p.28)
5. Metabolic rate
6. Clothing insulation (ANSI and ASHRAE 2004, p.4, Givoni 1969, p.21)

All six of these factors may vary with time, however this standard only addresses thermal comfort in a steady state.

[1] - ANSI: American National Standards Institute
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

Thermal comfort can be achieved by many different combinations of these variables and therefore also by the use of many fundamentally different technical systems (Fanger 1970, p.15).

In addition to the independent environmental and personal variables influencing thermal response and comfort, other factors such as nonuniformity of the environment, visual stimuli, age, outdoor climate (ASHRAE 2001, p.8.12) and health condition (Gut and Ackerknecht 1993, p.46) are generally considered secondary factors which may also have some effect. “Although ethic differences are not of importance, the geographical location plays a role because of the habits and of the acclimatization capacity of individuals” (Gut and Ackerknecht 1993, p.41).

“Each one of the primary factors can vary independently of the others and usually these variations will cause changes in several of the secondary factors” (Givoni 1969, p.21). Studies by Rohles and Nevins (1971) and Rohles (1973) on 1600 college-age students revealed correlations between comfort level, temperature, humidity, sex, and length of exposure (ASHRAE 2001, p.8.12).

For given values of humidity, air speed, metabolic rate, and clothing insulation, a comfort zone may be determined. The comfort zone is defined in terms of a range of operative temperatures that provide acceptable thermal environmental conditions, or in terms of the combinations of air temperature and mean radiant temperature that people find thermally acceptable. In most practical cases, where the relative air speed is low (<0.2 m/s, 40 fpm) or where the difference between mean radiant temperature and air temperature is small (<4°C, 7°F), the operative temperature can be calculated with sufficient approximation as the mean value of air temperature and mean radiant temperature (ANSI and ASHRAE 2004, pp.4-20).

ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy specifies conditions or comfort zones where 80% of sedentary or slightly active persons find the environment thermally acceptable. According to ASHRAE (2001, p.8.12) because people typically change their clothing for the seasonal weather, this standard specifies summer and winter comfort zones appropriate for clothing insulation levels of 0.5 and 0.9clo (0.078 and $0.14 m^2K/W$) respectively.

“The warmer and cooler temperature borders of the comfort zones are affected by humidity and coincide with lines of constant effective temperature. In the middle region of a zone, a typical person wearing the prescribed clothing would have a thermal sensation at or very near neutral. Near the boundary of the warmer zone, a person would feel about +0.5 warmer on the ASHRAE thermal sensation scale; near the boundary of the cooler zone, that person may have a thermal sensation of -0.5” (ASHRAE 2001, p.8.12). The main metric of comfort in ASHRAE Standard 55 is the Predicted Mean Vote (PMV), an index that predicts the mean value of the votes of a large group of persons on a 7-point thermal sensation scale. In addition, the Predicted Percentage of Dissatisfied (PPD) is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from the PMV (Ubbelohde et al. 2003, p.3).

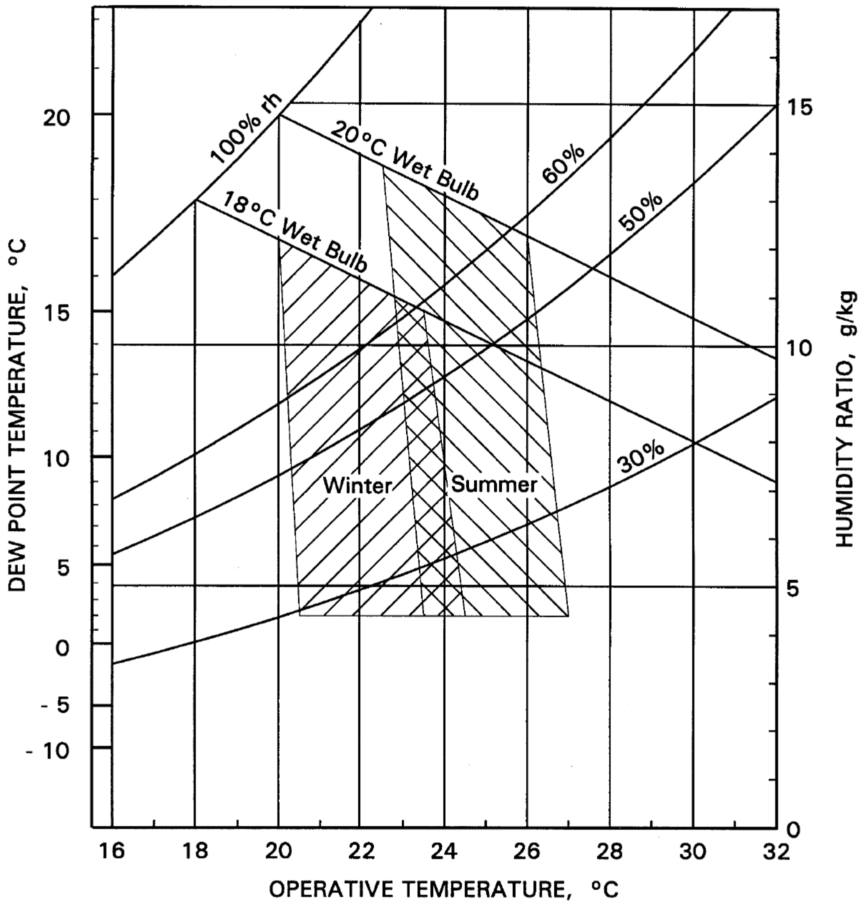


Figure 4: ASHRAE summer and winter comfort zone, Source: ASHRAE 2001, p.8.12

Air movement affects body cooling. It does not decrease the temperature but causes a cooling sensation due to heat loss by convection, and increased evaporation from the body. As the velocity of air movement increases, the upper comfort limit is raised. However, this rise slows as higher temperatures are reached (Olgyay 1963, p.19). Based on a study of the effect of air velocity over the whole body, thermal acceptability is unaffected in neutral environments by air speeds of 0.25 m/s or less (ASHRAE 2001, p.8.13).

Difference in Comfort Zones

The comfort zone varies between countries, climates, and cultures and is defined and characterised by a range of standards. According to Ubbelohde et al. (2003, p.2) the most accepted standard for thermal comfort in the United States and internationally is published by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). The document, ASHRAE Standard 55, has been developed and revised based on laboratory data and field studies over the last five decades.

Other standards, such as DIN 1946/1994, SIA[1], CIBSE[2] (1990), and ISO 7730 (1990), are used in Germany and some other countries. The summer and winter comfort zones and their cooler and warmer boundaries also vary between the standards. This table shows the differences between the minimum temperatures of summer and winter comfort zones in some of these standards.

Table 2: Minimum temperatures of summer and winter comfort zones in different standards, Source: Müller 2008, p.31

Comfort Criteria	DIN 1946/2 (1/1994)	SIA V382/1 (1992)	CIBSE (1990)	ISO 7730 (1990)
Δt_{az}	≤ 2 K	<2 K	<3 K	<3 K
$T_{0,1\ \text{min, Winter}}$	21 °C	19 °C	20 °C	NA
$T_{0,1\ \text{min, Summer}}$	21 °C	22 °C	22 °C	NA

This variance in comfort zones is not a new phenomenon. According to old literature, the British comfort zone once lay between 14.4° and 21.1° C, the United States between 20.6° and 26.7° C, and the tropics between 23.3° and 29.4° C with relative humidity between 30 and 70% (Brooks 1950, p.246). Also, a German standard was suggested as 20.8° C with 50% relative humidity (Olgyay 1963, p.17).

1 - SIA: Schweizerischer Ingenieur- und Architektenverein.
2 - CIBSE: Charted Institute of Building Services Engineers, U.K.

Climate Responsive Buildings

The shelter is the main instrument for fulfilling comfort requirements. It modifies the natural environment to approach optimum conditions of livability. It should filter, absorb, or repel environmental elements according to their beneficial or adverse contributions to man's comfort (Olgyay 1963, p.15). Climate responsive buildings are fundamentally more responsive to their climate and location (than normal buildings). These buildings take advantage of their external environmental conditions to regulate the internal environment, matching thermal comfort conditions. This reduces the need for the active use of HVAC systems, thus reducing energy requirements. “The main objective of climatic design is to provide comfortable living conditions with a minimum and meaningful input of artificial energy” (Gut and Ackerknecht 1993, p.69). “The ancients recognized that regional adaptation was an essential principle of architecture” (Olgyay 1963, p.4). Climate responsive buildings in continental climates must respond to both summer and winter climates. For an overall annual optimisation through architectural design, both heating and cooling loads must be considered. The heating load of a continental climate responsive building is firstly minimized by increasing solar gains and reducing heat loss in cold periods. The cooling load is minimised by reducing solar gains through windows, reducing internal gains, and through the use of natural cooling techniques such as natural ventilation and evaporation cooling.

Structures for residential purposes are generally occupied throughout day and night. They should therefore be designed for an optimisation over the whole period. Special attention must be paid to sleeping areas and their nighttime conditions, as the body is more sensitive to discomfort when at rest (Gut and Ackerknecht 1993, p.48). All building characteristics (building form, compactness, orientation, elongation, building geometry, and room location and arrangement) and thermal envelope components (walls, roof, floor, and apertures) affect the building’s energy consumption, and must therefore be studied in order to obtain a climate responsive house.

Building

Building Shape

Housing forms and building shapes should conform to favourable or adverse impacts of the thermal environment. Accordingly, certain shapes are preferable to others in a given surrounding (Olgyay 1963, p.19). Building shape and construction greatly influence how much of the climate and internal loads are actually translated into heating and cooling requirements (Brown and Dekay 2001, p.45).

Compactness and Elongation

The heat exchange between the building and the environment depends greatly on the exposed surfaces. A compact building gains less heat during the daytime and loses less heat at night. Therefore the ratio of surface to volume is an important factor (Gut and Ackerknecht 1993, p.81). Loss of heat through the building envelope can be reduced by creating a compact building form. The smaller the area of the outside wall per heated volume, the less energy will be required to operate the building (Goulding et al. 1992, p.68).

In general, where little heat exchange between the interior and the environment is desired, the surface to volume ratio should be small. The indoor temperature will be close to the average outdoor temperature. Where heat exchange is desired, the surface to volume ratio should be bigger (Gut and Ackerknecht 1993, p.82). Therefore the optimal building form varies with the climate. Window and wall orientation directly affects the gain and loss of a building's energy. Window orientation is particularly important for energy gain as levels and angles of solar radiation vary between seasons. Accordingly, the relationship between wall area (of different orientations) and elongation is very important.

For a building with little or no window openings, a very compact building form, such as a square, is the optimum form. This results in minimal heat loss in winter and heat gain in summer. According to Victor Olgyay (1963, p.90) in cool climates, excessive heat loss from the low winter temperature overrules the benefits of solar heat gain through an elongated structure in the east-west direction, pressing it into a nearly square shape. Today however, in buildings with insulated thermal envelopes and with high window area, a building form with optimum window area is more important than one that is compact. However, compactness is also an important factor. With the availability of external adjustable shading devices with up to 0.1 shading coefficient (up to 90% shading efficiency), the high solar heat gain through windows in winter is more important than low solar heat gain in summer. Therefore an important factor for introducing an optimal climatic building form is a shape with the ability of high solar gain especially in underheated periods.

Orientation

The overall issue of building orientation is composed of many factors. These include local topography, privacy requirements, a pleasurable outlook, noise reduction, and the climatic factors of wind and solar radiation (Olgyay 1963, p.53). Building orientation affects the indoor climate by regulating the influence of two distinct climatic factors:

- Solar radiation and its heating effect on walls and rooms facing different directions
- Ventilation problems associated with the relationship between prevailing wind direction and building orientation (Givoni 1969, p.191).

“To define the optimal climatic orientation of a building, three factors have to be considered:

- Solar radiation
- Prevailing wind
- Topography, geomorphology and vegetation” (Gut and Ackerknecht 1993, p.79).

In terms of orientation, the effect of the sun's heat can be both positive (in cold periods) and negative (in hot periods). Thus, for optimum climatic orientation the quantities of solar radiation falling on different sides of a building at different times must be considered.

An optimum orientation would maximizse radiation in the underheated period (when radiation is desired), while simultaneously minimising insolation in the overheated period (when it is to be avoided), thus balancing these two periods (Gut and Ackerknecht 1993, p.80, Olgyay 1963, p.12). Not only must the orientation allow optimum seasonal heat gain in overheated and underheated periods, but it must also achieved a daily heat balance in the building. “Ideally, we would have temperatures in the comfort zone and constant throughout the day. The orientation which most nearly produces these requirements is closest to balanced conditions” (Olgyay 1963, p.60).

Optimal climatic orientation has always been considered to be an important factor in architecture as can be seen in Vitruvius’ writings on the subject and in his treatise “On Architecture”. Later, in the first half of nineteenth century, several people (Augustin Rey, J. Pidoux and Gaston Bardet (1913), Felix Marboutin (1931), Henry Wright (1936), Gaetano Vinaccia (1943), Ludwig Hilberseimer (1944), and Jean Lebreton (1945), for example) have selected the optimal orientation through different methods. Their findings have suggested different orientations from southwest to southeast and even as far as north[1], but recent studies emphasise either true south or an orientation between south and southeast. As Goulding et al. (1992, p.52) for example explains, south facing surfaces receive more solar radiation in winter and less in summer compared to surfaces at other orientations. According to Felix Marboutin (1931), to provide the best living conditions (warmth in winter, coolness in summer) principal building facades should face south. But the ideal orientation must vary between climates. The ideal building orientation for Tabriz will therefore be determined by modelling a range of buildings with simulation programs.

Floor Plan Design (Room Location and Arrangement)

Different rooms of a house have different desired conditions throughout the day. They also receive varying amounts of energy from their surrounding environment (particularly from the sun) and loose varying amounts of energy according to their location. Therefore, designing a building’s floor plan, its location of spaces, and arrangement of rooms affects its energy consumption. Room location

[1] - In this part and throughout the treatise this relates to the northern hemisphere.

and orientation must match the desired conditions for each room. Heat gain and loss (and especially solar heat gain) of each room must be compatible with its required indoor condition.

As a result, important living rooms must be located and oriented toward environmental advantages (Gut and Ackerknecht 1993, p.83), and uncontrolled spaces toward environmental disadvantages. For example, uncontrolled and unimportant spaces must be located to the north in cold climates of the northern hemisphere and living spaces must be located to the south. According to Olgyay (1963, p.62) most importantly, to secure desired conditions in living areas, the times during which they are used (such as in dayrooms or bedrooms) should be considered in the evaluation of orientation. “When designing the floor plan of a building, apart from the functional arrangements, room connections and privacy requirements, the following aspects should be considered:

- At what time of the day will the room be used?
- Is the room of prime importance or is it an auxiliary space” (Gut and Ackerknecht 1993, p.83).

For the floor plan itself many recommendations exist for room exposures. As an illustration, a table by Jeffrey E. Aronin is shown below, suggesting sun orientations for various rooms in residential buildings above the 35° latitude (Olgyay 1963, p.62).

Table 3: Suggested sun orientation for rooms, Source: Olgyay 1963, p.62

	N	NE	E	SE	S	SW	W	NW
Bedrooms	●	●	●	●	●	●		
Living				●	●	●	●	
Dining			●	●	●	●	●	
Kitchen			●	●	●	●		
Library	●	●						●
Laundry	●	●						●
Play				●	●	●	●	
Drying yd				●	●	●	●	
Bathrooms	●	●	●	●	●	●	●	●
Utility	●	●						●
Garage	●	●	●	●	●	●	●	●
Workshop	●	●						●
Terrace			●	●	●	●	●	
Sun Porch				●	●	●	●	

The zoning of a floor plan, and especially the connection of different rooms with each other and with the outdoor environment, also affects the energy consumption of a building. To reduce the effect of an outdoor environment on an indoor environment, their direct connection via windows and doors must be reduced or achieved via a buffer zone.

Thermal Envelope

The envelope of a building separates the indoor space from the external environment and in this way modifies or prevents the direct effect of climatic variables such as external air temperatures, humidity, wind, solar radiation, rain, snow, etc. This envelope is usually composed of two types of material, opaque and transparent, although translucent materials are sometimes included (Givoni 1969, p.113). Its quantitative effect depends on its thickness and thermophysical properties (Givoni 1969, p.113). Both transparent and nontransparent parts of a building's thermal envelope can lose heat, by transmission, through thermal conduction. The thermal envelope of a building can also lose thermal energy through infiltration and radiation. Increasing the thermal resistance of building elements will reduce their conduction heat loss. This can be achieved via thermal insulation for nontransparent elements (i.e. walls, roof, and floor) as well as multi layer glazing (especially when filled with low-conductivity gases). Transparent elements of the thermal envelope can also gain heat from direct and diffuse solar radiation.

Windows

The windows of a building's thermal envelope lose energy by conduction through both their glass and frame. Heat can also be lost by infiltration around the window frame as well as by radiation to the external environment through the window's glazing surface. Windows also allow the solar radiation to enter the building through their glass surfaces during both heating and cooling periods. They are therefore a crucial element for both heat loss and heat gain.

Because of its much lower resistance and higher thermal conductivity, much more heat flows through glazing than through the insulated skin, per unit of area (Brown and Dekay 2001, p.46). Thus, windows lose more heat than opaque elements of the thermal envelope. To reduce the heat loss of windows through conduction, the thermal resistance of their glass and frame must be increased. This, as well as the reduction of heat loss through the glass, is achieved through insulated or multi layer glazing (double, triple or quadruple) and the use of gas in the void between the glass layers.

In winter, thermal energy can radiate through windows from the warm internal environment to the cold external environment. Therefore the windows must be controlled regarding radiative heat loss. The use of low emissivity (Low-E) glazing reduces winter heat loss (via transmission) through transparent parts of the thermal envelope. "Low-emissivity glass is produced by coating the glass with a layer of selective low-emissivity long-wave radiation. This coating reduces the radiant heat loss from the glazing, which is in the long-wave part of the radiation spectrum" (Givoni 1998, p.60). Coating the interior face of a glass surface with a thin layer of metal or metallic oxide reflects a significant amount of radiant heat, reducing the heat loss through radiation.

To reduce heat loss, especially via thermal radiation, movable insulation systems can also be used for glazing surfaces. This insulation, in the form of movable panels, curtains, and shutters, covers the windows during winter nights. Some notable insulation systems include removable Styrofoam panels, adjustable multi-roller shades, drapes, fiberglass sandwich panels (Kalwall), quilted shades, multi-layer Mylar shades, Styrofoam bead-filled cavities (Beadwall), interior shutters, exterior roll-down screens (Rolladen), and fold-up shutters. Covering windows during winter nights with the above mentioned systems or other adjustable shading devices reduces the heat loss through windows via transmission.

To reduce heat loss via infiltration, all elements and connections of the window, frame and opening must be airtight.

Walls

The walls separate the indoor and outdoor environments and modify the effect of climatic variables on indoor conditions. They lose and gain heat and so affect the indoor environment. Wall orientation affects levels of heat loss and heat gain.

The interior surface temperature of a wall affects the radiant temperature which in turn greatly affects the indoor thermal comfort. Therefore walls must be controlled to prevent heat transfer by conduction between inside and outside. This can be achieved by insulating the walls.

Roofs

Of all the building components, the roof is the most exposed to the climatic elements. The impact of solar radiation on clear summer days, nighttime and winter heat loss by longwave radiation, rain, and snow all affect the roof more than any other part of the structure (Givoni 1969, p.138). Because of the varying angle of incidence between the summer and winter sun (higher solar altitude in summer, lower in winter), horizontal surfaces receive more solar radiation in summer and less in winter. Therefore vertical surfaces are preferable. A building can gain more heat from the roof in summer, when it is not needed, and less in winter, when it is needed. Therefore heat flow through the roof must be more controlled by increasing thermal resistance with insulation material.

Colours of the Walls and Roofs

“The colors of the building's external envelope determine the impact of solar radiation on the building - in effect, what fraction of the solar energy striking the building is actually absorbed at the building's envelope, affecting its heat gain and indoor temperatures, and what fraction is reflected away, without any effect on the building's thermal conditions” (Givoni 1998, p.74). Increasing the thermal resistance of walls and roofs, however, limits the effect that their colours have on the internal environment.

Materials

Heat transfer in buildings takes place in the following four ways: by conduction, convection, radiation and evaporation (or condensation). The material properties which affect the rate of heat transfer in and out of a building, and consequently the indoor thermal conditions and comfort of the occupants, are:

- Thermal conductivity, resistance and transmittance
- Surface characteristics relating to radiation – absorptivity, reflectivity, and emissivity
- Surface convective coefficient
- Heat capacity
- Transparency to radiation of different wavelengths (Givoni 1969, p.96).

Thermal Insulation

The amount of heat that flows through a building's skin due to a temperature difference between inside and outside is a function of the magnitude of that difference, the resistance to heat flow of the skin materials, and the area of the skin. Insulation increases the thermal resistance of opaque elements of thermal envelopes, reducing unwanted heat loss or gain and thus decreasing the building's heating and cooling energy consumption. Some insulation materials include cellulose, rock wool, fiberglass, polystyrene, urethane foam and vermiculite. As they have much higher thermal resistance than building materials, "the resistance of opaque walls increases dramatically as insulation is added to the wall" (Brown and Dekay 2001, p.46).

Insulation plays a role in keeping wall surface temperatures warm during cold periods. This increases comfort by reducing drafts and the area of cold surfaces within the occupants' radiant field (Brown and Dekay 2001, p.46).

There are two kinds of insulation: internal and external. To moderate day and night temperature fluctuations, sufficient thermal storage mass must be placed throughout a building. This is particularly important for buildings with continual occupancy (e.g. houses) and for those using solar radiation for heating. Therefore, external insulation must be used in these buildings to add the mass of external walls, roof and floor to thermal storage mass of the building.

Bioclimatic Chart

"Olgyay was the first to propose a systematic procedure for adapting the design of a building to the human requirements and climatic conditions. His method is based on a "Bioclimatic Chart"" (Givoni 1969, p.280). This chart shows the comfort zone in the centre. The climatic elements around it are shown by means of curves which indicate the nature of corrective measures necessary to restore the feeling of comfort at any point outside the comfort zone (Olgyay 1963, p.22). The following figure is a bioclimatic chart.

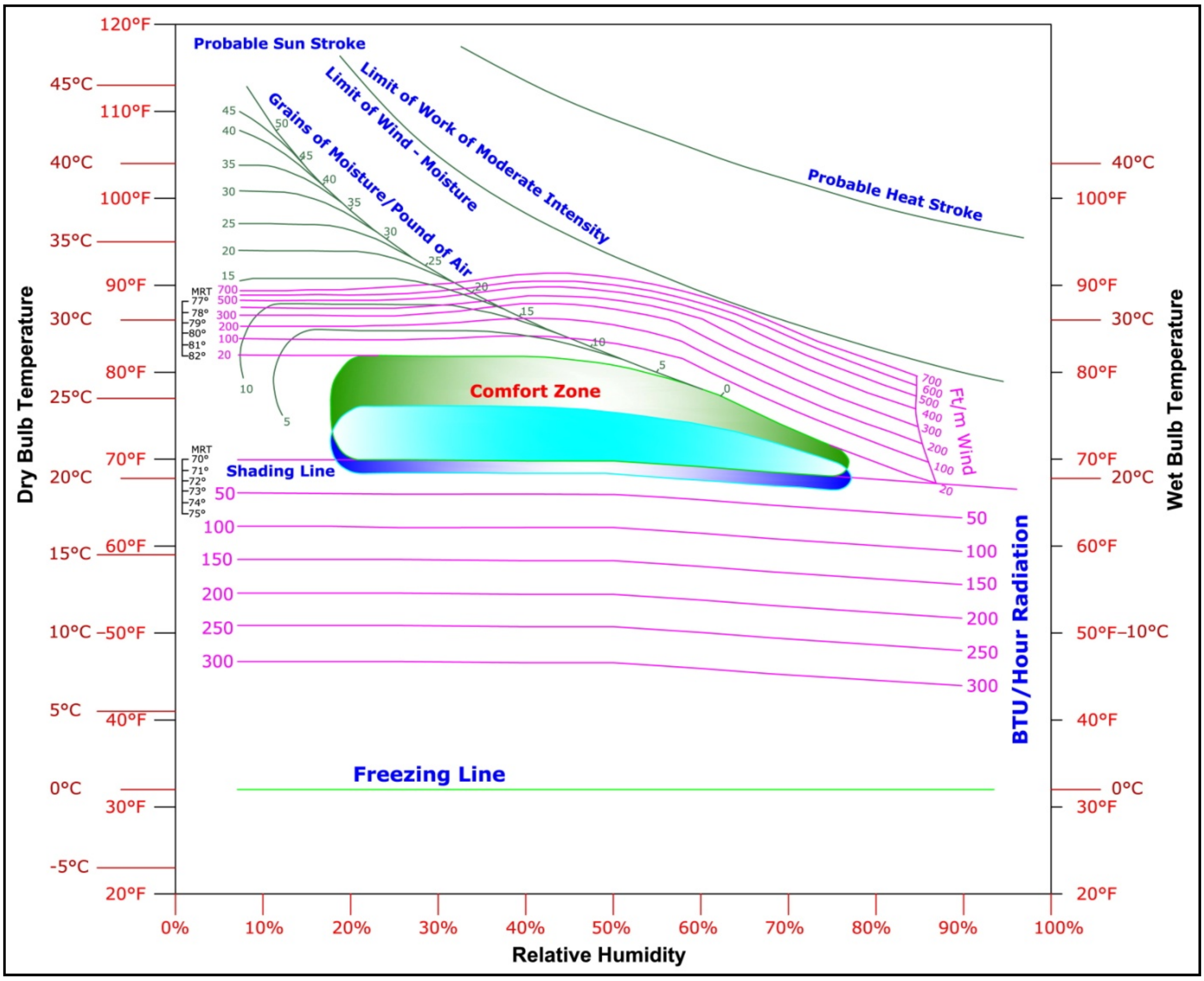


Figure 5: Bioclimatic chart, Source: Olgyay 1963, p.22 (my drawing)

Building Bioclimatic Chart

The system based on the bioclimatic chart "is limited in its applicability as the analysis of physiological requirements is based on the outdoor climate and not on that expected within the building with question" (Givoni 1969, pp.281-282). "An important extension of the Olgyays' work was made by Baruch Givoni" (Watson and Labs 1983, p.33) leading to Building Bioclimatic chart. The building bioclimatic chart, prepared by Givoni in 1969, shows the building and occupancy related parameters under which the interior comfort conditions can be achieved during unfavourable external climate conditions.

A building bioclimatic chart is formed by plotting the suitability of ventilation, air temperature reduction, and evaporative cooling or air-conditioning on a psychometric chart. These values apply to ambient conditions combining different temperature amplitudes and vapour pressures (Givoni 1969, p.288).

The building bioclimatic chart is subdivided into zones that define passive solar heating and cooling strategies, based on the work of Milne and Givoni (Watson 1979, pp.96-113) and later work by Givoni (Brown and Dekay 2001, p.54, Givoni 1998, pp.22-45).

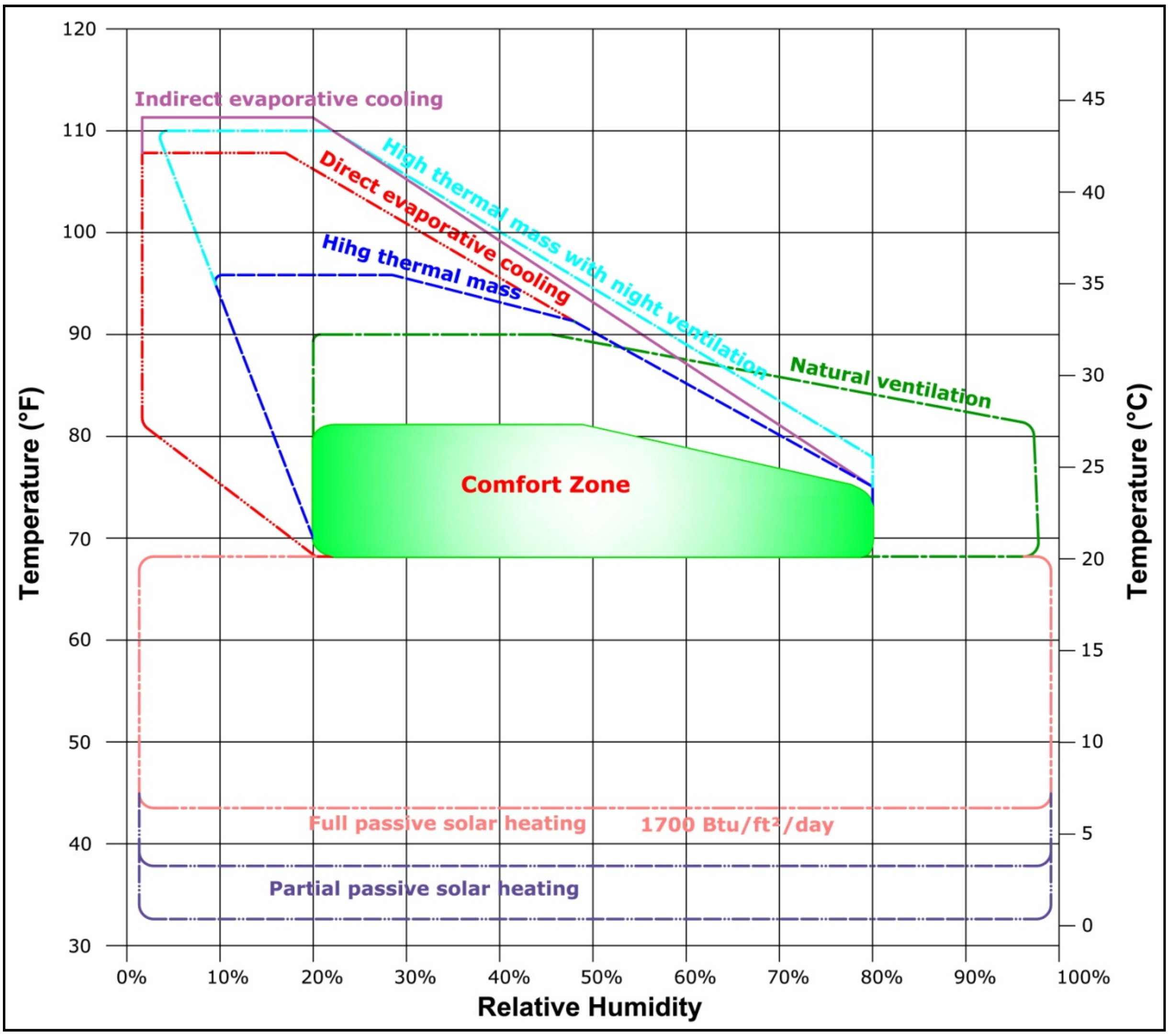


Figure 6: Building bioclimatic chart (for skin-load-dominated buildings), Source: Brown and Dekay 2001, p.54 (my drawing)

Heating

External Gains

Solar Heating

The sun radiates large amounts of energy, which reaches the earth's surface in the form of radiative energy. This energy is converted into thermal energy when the sun's rays strike the surface of the earth. This energy can then be used to heat the spaces of a building. "Solar energy is used to heat buildings in three ways: (1) passive (architectural) system, (2) active (mechanical) system and (3) hybrid system" (Goulding and Lewis 1997, p.21, NCSC 1999, p.2).

A solar heating system has four main functions:

1. Collection of the sun's heat that falls upon the building's surfaces during the winter days
2. Storage of this heat, so that it can be used during the night or during sunless periods
3. Distribution of the stored heat throughout the house for comfort and energy efficiency
4. Retention of the heat in the building by reducing or eliminating usual sources of heat loss (Watson 1985, pp.16-17).

A passive solar system is "a system that collects, stores, and redistributes solar energy without the use of fans, pumps, or complex controllers" (Lechner 1991, p.110). It an architectural system, in which the materials and building elements such as windows, walls, floors, and roofs are used to collect, store, release, and distribute heat in the building.

Passive Solar Heating Systems[1]

There are three basic passive solar systems for heat gain: direct gain, indirect gain and isolated gain. Each of these basic systems has subsystems. The passive solar heating systems and their subsystems are stated in following table:

Table 4: Passive solar heating systems, Source: Based on data from Goulding et al. 1993, p.66 and Williams 1983, pp.10-142 (my revisions)

	Direct	Indirect	Isolated
South aperture	Non-diffusing	Mass wall	Sunspace
	Diffusing	Trombe wall	Barra-Costantini
	Direct gain sunspace	Water wall	Isolated wall collector
		Remote storage wall	
		Simple U-Tube collector	
		Thermosiphoning wall	
Shaded roof aperture	Clerestory	Shaded storage roof pond	Black attic
Roof aperture	Direct gain roof	Roof pond	
Remote aperture			Thermosiphon rock bed
			Thermosiphon storage wall

Direct Gain

The direct gain, as a simple system, consists of south-facing glazing and an occupied space behind it in which the functions of a solar heating system occur. In direct gain systems, sunlight admitted directly to the living spaces through south-facing windows is converted to thermal energy, thus warming the interior space.

Non-Diffusing Direct Gain System

A non-diffusing direct gain system allows the sunlight to fall on a concentrated area of thermal mass in heated space.

Diffusing Direct Gain System

A diffusing direct gain system diffuses or reflects the sunlight so that it is distributed evenly over a large area of thermal mass.

1 - The part "Passive Solar Heating Systems" is based on the research done by the present author based on different references, the most important of which includes the works by Goulding 1993, Williams 1983, Lechner 2001, Luxan 2005, and the Arizona Solar Centre 2005.

Direct Gain Sunspace

Direct gain sunspace is used in buildings with a sunspace system. In this system, all or some of the common walls between sunspace and heated space are covered with a glazing surface and the solar radiation is passed through the sunspace to finally enter the heated space.

Indirect Gain

The indirect gain system combines the collecting, storage, and distribution functions within the part of the building envelope enclosing the living spaces (Goulding et al. 1993, p.68).

Mass Wall

The mass wall system consists of an external glass surface and a thermal storage mass, located as the south-facing wall of the living space. Thermal storage mass is commonly constructed of concrete, stone, brick, or composites of brick and block construction.

Trombe Wall

The Trombe wall system uses an external, south-facing glazing surface and a masonry or concrete wall behind. It requires two vents, at the top and bottom of the storage mass, to allow air to circulate through to the heated space.

Water Wall

The water wall system consists of a south-facing glazing surface and water containers directly behind the surface, i.e., the water containers are placed between the heating space and the glazing surface.

Remote Storage Wall

"The remote storage wall is similar in form to the Trombe wall, but is insulated on the room side, to prevent energy transmission by conduction and radiation, all heat transfer is by convection, possibly fan-assisted" (Goulding et al. 1993, p.69).

Simple U-Tube Collector

In this system, there is a south-facing vertical or tilted glazing surface and an insulation layer behind (together forming a box). In addition, a metallic absorber is located between the window and insulation.

Thermosiphoning Wall

A thermosiphoning wall has a south-facing window, a wall behind it, and a metallic absorber located between the window and wall. There are two vents, at the top and bottom of the wall, through which natural convection will occur between the absorber space and heated space.

Roof Pond

Roof pond systems use water containers (plastic bags) on the roof for thermal storage, and a movable insulation system to cover the water bags during winter nights and summer days.

Shaded Storage Roof

Shaded storage roofs are similar to the roof pond system but differ in that water bags are located in a solar attic below a pitched roof with south-facing glazing.

Isolated Gain

In isolated gain systems, solar collection occurs in a separate area of heated spaces. Most of the collected heat in this space will be transferred to living spaces via convection as well as a little via radiation.

Sunspace System

In sunspace systems, a sunspace is used on the south side of the building to collect solar radiation. A sunspace is a small closed space with a glazing surface, attached to the south side of a building.

Barra-Costantini System

The Barra-Costantini system is a variation of the convective loop, which uses a nonmassive wall as a collector and a massive ceiling structure as the heat storage element (Lechner 1991, p.129).

Black Attic System

The black attic system uses a shaded roof aperture to collect sunrays. In this system, there is an isolated space between the roof and the living space (loft), in which the functions of a solar heating system occur.

Thermosiphon System

The thermosiphon system consists of a simple U-Tube collector made of a glazing surface over a metallic absorber, an insulation layer at the back of the collector, and a remote storage mass.

There are two kinds of thermosiphon systems with different storage masses. These are thermosiphoning rock bed and thermosiphoning storage wall systems.

Dual Gain

These systems are designed to profit from the main advantages of each category involved and are the combination of direct, indirect, and isolated gain systems.

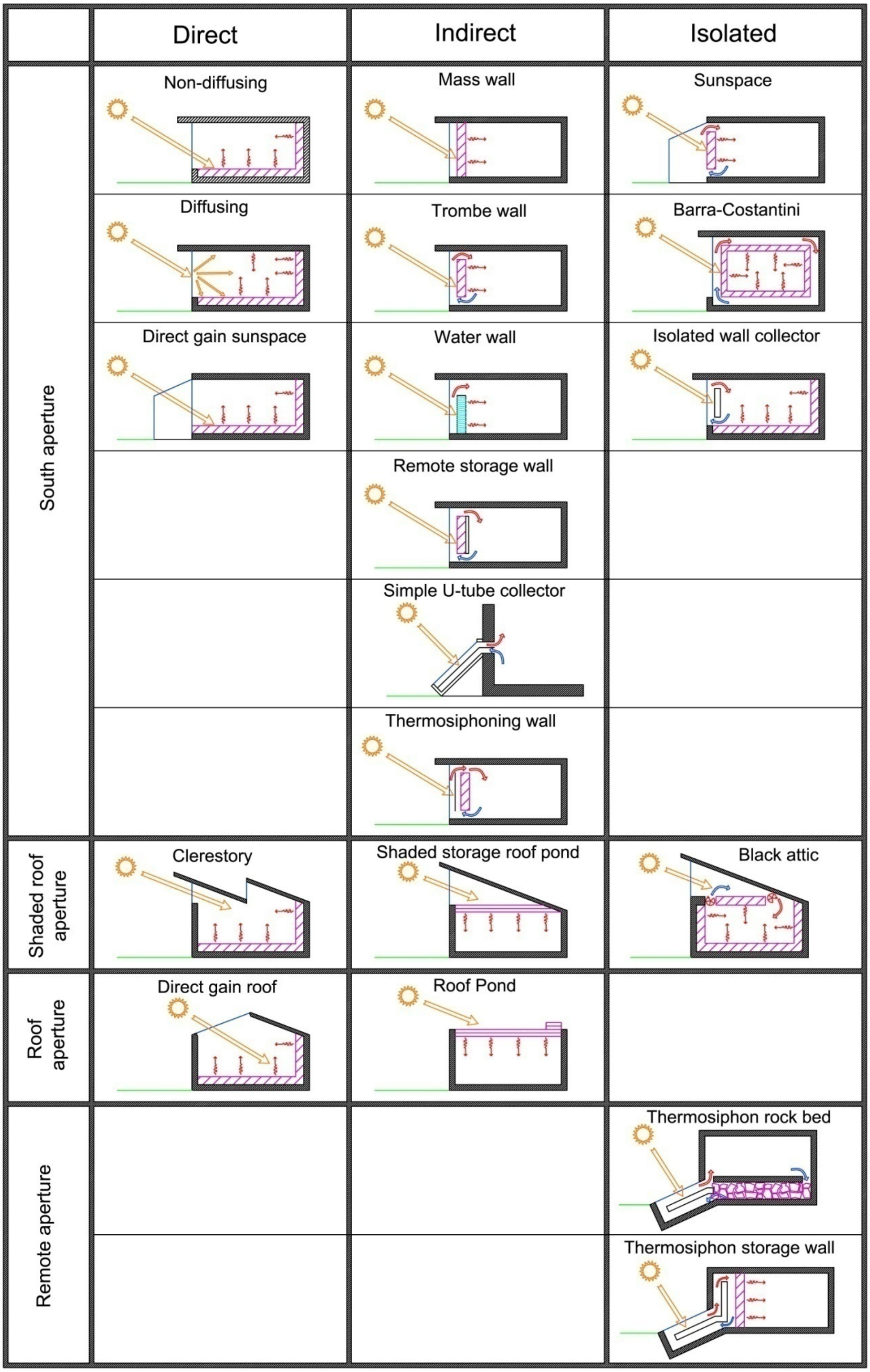


Figure 7: Passive solar heating systems, Source: Goulding et al. 1993, p.66, Williams 1983, pp.10-142 (my revisions and drawing)

Internal Gains

Household Appliances

Electrical equipment and appliances operating in a space contribute heat to that space as a by-product of their operation. The amount of heat generated is a function of the type and efficiency of equipment the amount of equipment, and how often it is operated. "All of the electric energy that goes into equipment, such as electric motors and computers, ends up as waste heat in the space" (Brown and Dekay 2001, p.44). Heat gain from household equipment can be reduced by use of energy efficient equipment.

Lighting

Electric lighting contributes heat to occupied spaces as an inevitable by-product of its function as illumination. Unless special heat removal techniques are used, almost all of the electrical power fed into the lights eventually generates heat in the occupied space. The amount of heat generated from lights is a function of the illumination level and the efficiency of the light source (Brown and Dekay 2001, p.42).

Occupancy Heat

The metabolic energy of inhabitants can contribute substantially to the amount of heat generated in the building. This heat may increase the cooling requirements or decrease the heating requirements in different climates and seasons. The amount of heat and moisture generated by people is a function of sex, age, activity and other factors. Most passive cooling systems cannot remove water vapour from the air; therefore, only the sensible air (that which raises the air temperature) gains are considered when determining the internal heat gains from people (Brown and Dekay 2001, p.39).

Cooling

Despite the research areas being the cold climatic region of Iran, the buildings of this region still require cooling in summer. To reduce a building's energy consumption, the cooling performance of buildings in warm periods of the year is also important. In cooling periods, the building can collect excess heat from sunrays, infiltration of hot outside air into the building, internal gains from occupants and their activities, and from equipment.

Passive Cooling

In the following figure, various passive cooling methods are shown.

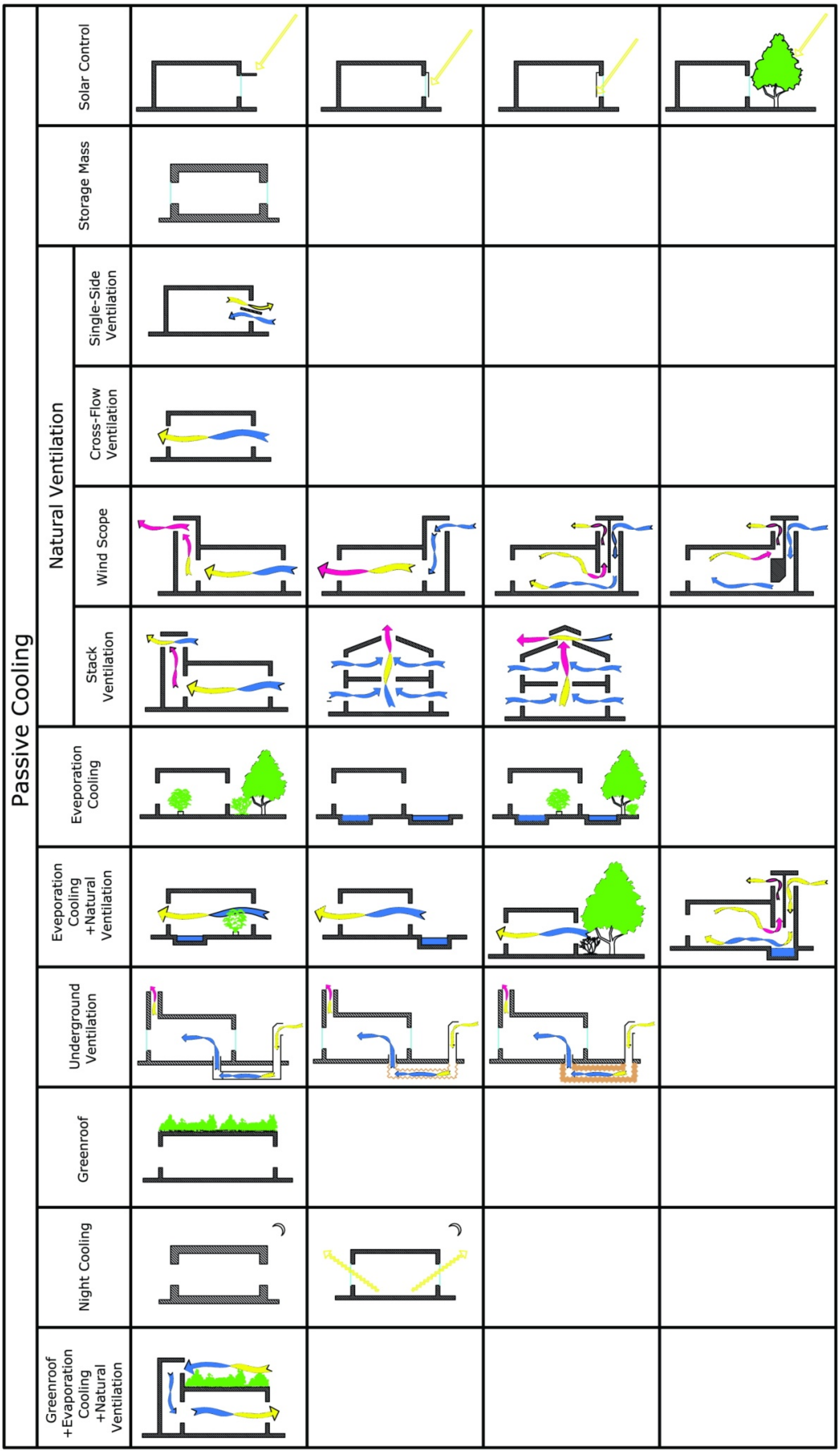


Figure 8: Passive cooling methods

Solar Control

To prevent overheating through solar gains in cooling periods and to decrease the cooling energy consumption of buildings, the glazing surfaces of buildings must be protected from unwanted solar gains in summer. This is achieved by blocking the sun's rays with shading devices before they reach the building.

To achieve a comfortable internal temperature, a number of measures such as solar control, external gains, internal gains, ventilation, and natural cooling should be taken (Goulding et al. 1992, p.73). South orientation of passive houses [or any energy efficient buildings] and their windows, aligned with large window areas, may result in overheating during summer. Therefore, the building's apertures, especially in sunny climates, must have proper shading devices (Graf 2003, p.25). Shading devices must be correctly selected and designed.

Shading Devices

Shading devices are architectural and non-architectural elements which, with the use of seasonal difference of solar angles, provide shade on the glazing surface in warm periods while permitting the sunrays to enter the building in cold periods. Sun angles (particularly solar altitude angle) vary depending on the time of year. When necessary, this can be used to shade windows. Shading devices may be external, internal or mid-pane, fixed, movable or retractable, permanent or seasonal, horizontal or vertical, manual or automated. There are several kinds of exterior shading devices such as overhang, trees and vegetation, canvas awnings, exterior venetian blinds (awning type) and roller blinds, vertical fins, egg-crate and sunscreens as well as several types of interior shading devices such as venetian and roller blinds or draperies.

Shading systems, which are shaped according to the changing seasonal sun-path, can effectively control the sun's direct radiation. If designed correctly, they can also partially block diffuse and reflected radiation during the summer but not winter. "Location, latitude, and orientation all contribute to the formulation of an effective [shading] device" (Olgyay 1963, p.63). Shading devices not only have a shading function, but can also serve as daylighting or insulating devices.

Shading Coefficient

Shading devices have different performance values and to evaluate this, the "shading coefficient" is used. According to Olgyay (1963, p.67) to compare the effective solar protection of different methods of shading the shading coefficient was used as a measure. The shading coefficient is the ratio of the total solar heat gain from the transmitted, absorbed and reradiated energy by the shade and glass combination compared to the total solar heat gain due to transmission, absorption and radiation by a single unshaded common glass. To evaluate the Shading Coefficient the transmitted radiation percentage of the shade-glass combination was related to a value 1.00 as a basic index for an unshaded regular double-strength (DS) window glass.

Shading devices have different shading coefficients varying between 0.10 and 0.91 (Olgyay 1963, pp.68-71, Brown and Dekay 2001, pp.48-49). Proper shading systems can therefore reduce summer solar heat gain through the façade by up to 90%. External shading devices have lower shading coefficients and are thermally more effective than interior shading devices because they prevent the sunrays from entering the building. "Movable vertical and horizontal shading devices can achieve very low shading coefficients, but view and potentially day-light will be blocked when fully employed. …The shading value of interior drapes varies substantially with color, and fabric, while other interior devices vary with color and degree of translucency" (Brown and Dekay 2001, p.48).

Typology of Shading Devices

Shading devices may be external, internal or mid-pane, fixed, movable or retractable, permanent or seasonal, horizontal or vertical, manual or automated.

Choice of shading strategy from different type and different shading devices is determined by building and site location, orientation, building type and use, sky conditions (the direct, diffuse and reflected solar radiation components) and other light sources such as intrusive street lighting (Low Energy Architecture Research Unit 2004, p.36).

Horizontal shading devices, such as overhangs, trellises and horizontal louvers are able to block high angle sunlight. They are therefore more efficient for south-facing facades in the northern hemisphere and north-facing facades in the southern hemisphere. However, vertical shading devices such as fins and vertical louvers can block low angle sunlight shining on the east and west facades thus making them more suitable for east and west-facing windows.

Positional Typology of Shading Devices

Shading devices may be located on the external or internal face of the facade, or within double- and triple- glazed windows or curtain wall systems. These can be described according to their placement as interior, exterior, and mid-pane shading devices. The exterior shading devices prevent the sunrays from entering the building, but interior shading devices keep the solar radiation between the glazing surface and the shading device. Therefore the exterior shading devices have lower shading coefficients and are more effective in reducing heat gains through windows than interior shading devices. "As an overall value one could conclude that the effectiveness increase 35% by using outside shade protection instead of an inside one" (Olgyay 1963, p.70). However, the simulation done in present research shows a much greater difference between the energy consumption of buildings with outside and inside shading devices.

External Shading Devices

External shading devices are shading elements which are used outside the occupied space, on the exterior face of a façade. They have two general forms: fixed and movable. Fixed external shading refers to horizontal overhangs, vertical fins, egg-crates, sunscreens, permanent awnings or shutters, and trees. Movable external shading devices consist of louvers, venetian blinds, awnings, and shutter systems that can be adjusted or fully retracted depending on climatic conditions.

Internal Shading Devices

Internal shading devices are movable or retractable elements that are used on the inner face of a window within an occupied space. They are typically in the form of roller or venetian blinds, curtains and draperies. Internal shading devices do not obstruct direct sunlight until it has passed through the glazing. The solar radiation is thus absorbed by the shading devices, converted into heat, and re-leased into the room. Consequently, they have limited thermal efficiency.

For internal shading devices colour, material, and degree of translucency have a significant influence on efficiency. Light coloured and reflective devices reflect some solar radiation back outside, but rough and dark colours absorb it. Therefore, light coloured and reflective shading devices are more efficient and have a better shading coefficient. The following table compares the effect of col-our of three shading devices:

Table 5: The effect of colour on the shading coefficient of internal shading devices, Source: Olgyay 1963, p.68

	Dark	Medium	Light	Aluminum
Vertical blind	0.75	0.65	0.56	0.45
Roller shade	0.81	0.62	0.41	-
Curtain	0.58	0.47	0.40	-

Insulated internal shading devices, when closed at night, can also act as a thermal barrier, greatly reducing winter heat loss through convection and thermal radiation.

Mid-Pane Shading Devices

According to Stack et al. (2002, p.9), mid-pane shading devices may be lo-cated between the panes of a double glazed unit or, in some commercial build-ings, within a curtain wall. If these equipments are accompanied by effective ventilation to the outside, they have the benefits both of external and internal shades. Heat gains are dissipated to the outside, but the shades are protected from the severity of the outdoor climate. Mid-pane devices are particularly effective in controlling glare. Typically, horizontal reflective louvers or venetian blinds are used to make a mid-pane shading device. Both control glare but reflective lou-vers are more effective at preventing solar heat gain.

Moveability Typology of Shading Devices

From the viewpoint of adjustability and moveability, there are two kinds of shading devices, namely fixed and movable (or retractable) shading devices. “Fixed devices are often preferred because of their simplicity, robustness, low maintenance and generally lower construction cost” (Stack et al. 2002, p.7). The shading coefficient for fixed shading elements depends on the exact design used.

Trees are especially variable by species, season if deciduous, and climate (Brown and Dekay 2001, p.48). But for adjustable shading devices the shading coefficient depends on the colour, material, use and adjustment quality.

Fixed Shading Devices

"There are two basic types of fixed shading devices: horizontal (overhangs) and vertical (fins). They can also be combined in different combinations (egg crates)" (Givoni 1998, p.62). The recessed window is also a type of fixed shading device. Fixed shading devices are relatively simple and inexpensive, and particularly effective at obstructing direct sunlight, but less effective against diffuse or reflected light (Stack et al. 2002, p.8).

Trees (and other vegetation) are fixed non-architectural shading devices. Fixed devices are neither adjustable nor retractable. Therefore, it is vital that their placement, their form and size are given due attention, for they need to be designed carefully with regard to the orientation of the aperture, sun-path, climate and the exact cooling period.

Movable Shading Devices

Movable shading devices are adjustable or retractable elements, which are manually operated or (fully) automated and can be adapted to suit the sun's position and the user's requirements. There are three forms of adjustable and movable shading devices. These include: external, mid-pane, and most commonly internal shading elements. Internal shading systems are inexpensive and easily manipulated.

Movable shading devices are more flexible than fixed devices. They respond better to the movement of the sun and can better control diffuse and reflected radiation and glare. In addition, movable and retractable devices can be manipulated to maximise daylight in overcast conditions. Unlike fixed shading, movable shading can be adjusted to allow a range of light levels to enter the room. However, its success depends on robust construction and correct use. But the automation of adjustable external shading can be costly, and energy efficiency depends mainly on climate and the frequency of adjustment (Stack et al. 2002, pp.7-9). Adjustable devices can permit simultaneous ventilation and shading while still providing daylight.

Adjustable and retractable external devices can be manipulated to exclude or admit sunlight when required, and can thus effectively control not only (low-angled) direct sunlight but also diffuse and reflected light. They are therefore able to modulate heat gain and are thermally efficient if used effectively. However, movable shading devices are normally operated by occupants and often without optimal manipulation, which can result in inefficient thermal use. Therefore using movable shading devices to prevent overheating (in comparison to fixed shading devices) is of less benefit.

Retractable Shading Devices

"Retractable shading devices may be retracted to the upper or side portion of the window, or totally removed. Internal blinds and curtains fall under this category, as do external devices such as fabric awnings, louvers and shutters. These devices avoid the compromise between adequate shading in summer and adequate sun access in winter" (Stack et al. 2002, p.9).

Overhang

An overhang is a horizontal projection that serves as a shading element for an aperture. It is the most usual form of external fixed shading devices. In the northern hemisphere overhang is especially effective for south-facing apertures, since they block out the high summer sun while permitting the low winter sun to warm the house.

When correctly designed and applied to a south-facing facade, the horizontal overhang can provide complete shading during midsummer and permit solar penetration in winter. The overhang length is determined by the width of the aperture and the latitude. The depth is determined by latitude, window height, and the vertical distance between the window and the overhang (Stack et al. 2002, p.8). But the present writer thinks that climate is the most important factor in this regard.

If an overhang is used for south-facing windows, it will have a shading coefficient between 0.20 and 0.30 (Brown and Dekay 2001, p.49) and can thus reduce 70-80% of the solar heat gain of the aperture.

Awning

An awning is a partially movable covering of canvas, venetian blind, bamboo or similar material, hinged on a metal frame at the top of a window to provide protection against the sun. It is an external shading device which is often adjustable, opening either outward or inward.

"Awnings are attached above and extend down and away from a window, effectively blocking direct sunlight. To help increase the reflection of heat, the awning should be a light color. Solid-surface awnings may require an opening between the top of the awning and the side of the house to vent hot air that accumulates. If winter heat gain is desired, awnings should be easy to remove for winter storage" (VELUX 12.07.2008). Awnings are more effective for south-facing windows. According to Olgyay (1963, pp.70-71) canvas awnings have a shading coefficient of about 0.25 but a venetian blind awning has a shading coefficient of 0.15.

Vegetation

Plants can have a cooling effect on buildings due to absorption of sunlight for photosynthesis which minimises reflection of sunlight and absorption of heat. They also provide evaporative cooling through evapo-transpiration and particularly shading. Vegetation, typically deciduous trees, vines, and shrubs, can provide seasonal external shading. Evergreen trees provide shade all year-round but deciduous trees and vines lose their leaves for the winter, thus providing protection from the summer sun while permitting the winter sun to reach the house. The most effective trees for shading are those, which drop their leaves at the start of the heating season and sprout their leaves at the start of the cooling season.

The shading effect of vegetation depends on the plant species, its leaf type, as well as placement and density. Vegetation is especially effective at providing protection against solar heat gain in summer on the east and west facades of buildings due to the fact that sunrays shine on low angles on these two facades.

Tree

The height, growth rate, branch spread, shape and being native to the area are important factors in choosing a tree as a shading device. Placement of the trees is very important, because they have to accurately shade apertures only in needed times. Solar heat gain through south-facing windows (in the northern hemisphere) in cold climates is very important in winter to reduce heating energy consumption. Thus, deciduous and especially evergreen trees should not be placed on the south side, since in the winter the evergreen trees and even bare branches of deciduous ones can significantly reduce the amount of sun reaching a house. They are, however, very effective for east and west-facing windows.

Different densities of trees provide different shading coefficients. Generally trees have a shading coefficient between 0.20 and 0.60 (Brown and Dekay 2001, p.49, Olgyay 1963, pp.69-71), for dense and sparse trees respectively. Therefore dense trees can reduce summer solar heat gain up to 80%.

Vine

The vines on trellises can provide effective shade and cool air. Vines have a number of excellent qualities: there is a variety for just about every soil type and hardiness zone; they grow to an effective density in just two or three years; they require little space on the earth and will grow in almost any configuration; and they provide colour, fragrance and privacy. As they grow, vines can climb trellises designed to shade windows or whole sides of houses. The trellises must be set far enough away from the house to allow air to circulate between the vines and walls.

Venetian Blind

A venetian blind is an adjustable, movable and retractable shading device, which comprises many thin parallel rotating slats. It can be located externally, internally or between the panes of a double or triple glazed window. Venetian blinds can be manually operated or fully automated but they must be properly adjusted to optimise thermal (and daylighting) effect.

Venetian blinds are able to control all kinds of sunrays including direct, reflected, and diffuse radiation at varying angles. They are therefore suited to south facing windows (in the northern hemisphere) and especially east and west facing windows. They can also provide glare control, privacy, and a daylighting function. Exterior and interior venetian blinds are the two main varieties.

Exterior Venetian Blind

Because external venetian blinds are adjustable, movable, and retractable, they are flexible and, if well manipulated, can respond to the movement of the sun. This means they can control not only direct radiation, but also diffuse and reflected radiation. Therefore they are thermally very efficient. Venetian blinds have a very low shading coefficient (0.10–0.15 (Brown and Dekay 2001, p.49)), and are thus capable of reducing solar heat gain through windows between 90% and 85%.

Interior Venetian Blind

Interior venetian blinds are adjustable, movable and can respond to the movement of the sun and control diffuse and reflected radiation. They are not, however, very thermally efficient as they do not exclude sunlight before it passes through the windows. Reflective interior venetian blinds reflect some of the solar radiation back outside and are thus more effective at reducing solar heat gain.

Interior venetian blinds act as shading devices, and are efficient in controlling glare, daylighting and addressing privacy issues. An insulated internal venetian blind also has an insulation function at night, when closed. According to Olgyay (1963, pp.68-70) internal venetian blinds have a shading coefficient between 0.45 and 0.75. In this way, they can reduce solar heat gain through windows from 25% to 55% of solar energy. In addition, light coloured, reflective venetian blinds are thermally more efficient.

Louver

Louvers are adjustable exterior shading devices which consist of a series of horizontal or vertical parallel slats. These slats are adjustable to moderate sunlight entering the room. Louvers are similar to shutters, but instead of an entire shutter pane they comprise of smaller slats.

They are capable of controlling direct sunrays with different altitude angles, reflected and diffuse radiation, and also vision, while permitting ventilation. They can be controlled from inside or outside the home. Adjustable louvers are of two kinds: horizontal and vertical. Horizontal louvers are suitable for south facing apertures because they can better prevent high summer sun and permit low winter sun to enter the room. However, in east and west facing windows, horizontal louvers cannot provide effective protection from the low-angled sunlight of morning and afternoon, whereas vertical louvers can.

Louvers have a very low shading coefficient, Olgyay (1963, p.71) says between 0.10 and 0.15. They are able to decrease 85% to 90% of the solar heat gain.

Roller Blind

A rolled blind is a kind of movable shading device with a series of small slats that are lowered along a track when shading is needed. The lower the shade is pulled, the further closed the slats become; when fully extended the blind allows no light to enter.

There are two kinds of roller blinds: exterior and interior. Exterior roller blinds can be highly effective in reducing solar gains but will eliminate views and impede ventilation. Internal roller blinds have a shading coefficient between 0.39 and 0.81 (Brown and Dekay 2001, p.49, Olgyay 1963, pp.68-70); therefore they can reduce solar heat gain through windows between 61% and 19%. Although internal roller blinds are not efficient, they can serve a heat insulation function through convection and radiation in winter.

Sunscreen

Sunscreens are fixed exterior louvers that reflect and/or absorb solar radiation. A sunscreen's effectiveness in shading a window depends on its light absorption properties and its geometry with respect to the window opening (Build It Green 11.12.2005).

Drapery

"Draperies and curtains made of tightly-woven, light-colored, opaque fabrics reflect more of the sun's rays than they let through. The tighter the curtain is against the wall around the window, the better it will prevent heat gain. Two layers of draperies improve the effectiveness of draperies for both summer and winter" (Doityourself 11.07.2008). Colour and fabric affect the amount of shading coefficient of draperies, which is in the range of 0.37 and 0.53 (Brown and Dekay 2001, pp.48-49).

Egg-crate

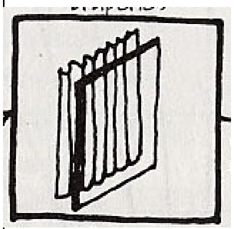
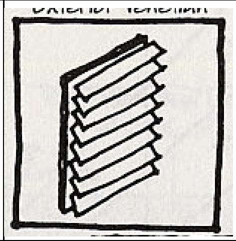
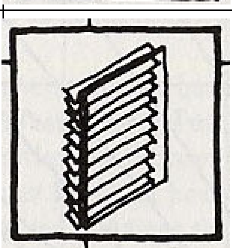
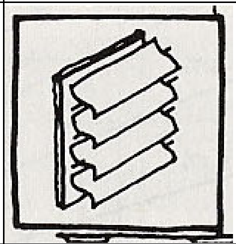
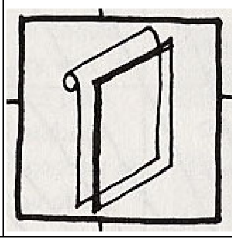
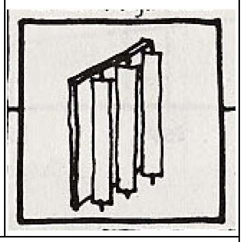
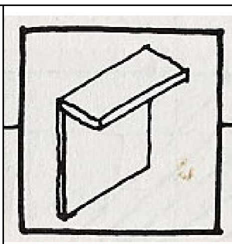
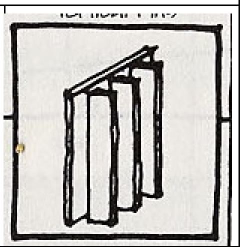
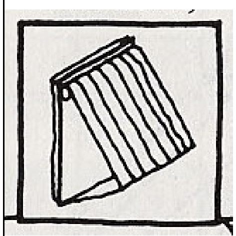
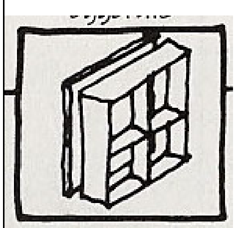
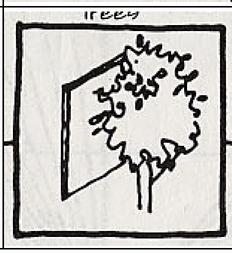
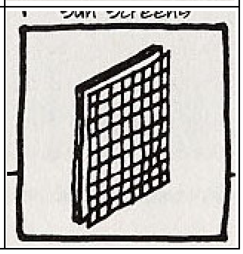
Egg-crate is a kind of external fixed shading device, which combines horizontal broken overhangs and vertical fins. "Egg-crate shading works well on walls facing southeast, and is particularly effective for a southwest orientation. Because of its high shading efficiency, the egg-crate device (deeply recessed windows) is often used in hot climates" (Precast / Prestresset Concrete Institute 2005, p.43). The egg-crates can block sunlight from all directions and thus they have a low shading coefficient between 0.10 and 0.30 (Brown and Dekay 2001, p.49).

Conclusion

To reduce cooling loads of buildings in summer, the windows must be protected from solar radiation with shading devices. Shading devices not only provide environmental comfort for human occupancy but also reduce the cooling energy consumption of buildings during cooling periods.

The shading devices must be correctly chosen and carefully designed to be thermally efficient and have an appropriate shading coefficient. Research must be undertaken into the most thermally efficient types of shading devices for energy efficient and passive houses in the research area (very cold climatic region of Iran).

Table 6: Shading coefficient of different shading devices, Source: Based on data from Brown and Dekay 2001, pp.48-49

	Internal				External			
	Shading Device	Shading Coefficient Max.	Shading Coefficient Min.	Shape	Shading Device	Shading Coefficient Max.	Shading Coefficient Min.	Shape
Movable	Drapery	0.53	0.37		Exterior Venetian Blind	0.15	0.10	
Movable	Interior Venetian Blind	0.75	0.45		Horizontal Adjustable Louver	0.15	0.10	
Movable	Interior Roller Blind	0.81	0.39		Vertical Adjustable Louver	0.15	0.10	
	External				External			
Fix	South Overhang	0.30	0.20		Vertical Fin	0.30	0.10	
Fix	Canvas Awning	0.35	0.20		Egg-crate	0.30	0.10	
Fix	Tree	0.60	0.20		Sunscreen	0.42	0.15	

Thermal Mass

Thermal mass works by storing heat and releasing it several hours later. This has advantages in warm periods because the internal air temperature does not rise as fast, thus helping to maintain thermal comfort. Instead, heat is stored in the fabric of the building. At night when the outside temperature is lower, it vents the heat stored in the building. The building is cooled and ready to store heat again the next day (Nottingham City Council 04.04.2007, p.8).

Figure 9: Cooling with thermal mass

Natural Ventilation

Ventilation acts to expel inside, unwanted, used hot air and replace it with fresh, cooler external air. If air supplying and extracting occurs using natural forces such as wind and buoyancy it is called natural ventilation.

"Natural ventilation is achieved by making use of the natural pressure differences surrounding a building, caused by the wind and stack effect. Natural ventilation is dependent on three climatic phenomena, wind velocity, wind direction and temperature difference" (Battle MacCarthy Consulting Engineers 1999, p.17). Natural ventilation occurs through different architectural elements, which connect inside and outside environments. Such elements include windows, wind towers, holes, vents, (underground) pipes, etc.

Ventilation serves three distinct functions. The first is to maintain the quality of the air in the building by replacing indoor air with fresh outdoor air. The second function is to provide thermal comfort by increasing the heat loss from the body and preventing discomfort due to moist skin. The third is to cool the structure of the building when the indoor temperature is higher than outside (Givoni 1969, p.230).

Natural ventilation has different cooling performance, such as:

- Replacing inside hot air with outside cool air
- Decreasing humidity and air pollution, which increase evaporation through the skin thus causing a cooling sensation.
- Increasing evaporation and thus cooling the space

The efficiency of natural ventilation is dependent on the opening orientation in comparison with wind direction, type and size of the inlet and outlet opening, wind speed, wind temperature, depth of the space etc. There are four different kinds of natural ventilation.

Single Side Ventilation

In single side ventilation with one opening, air flows in from a part of the opening and flows out from the other side. In the case of single side ventilation with two openings, air flows in from the lower vent and out from the upper opening.

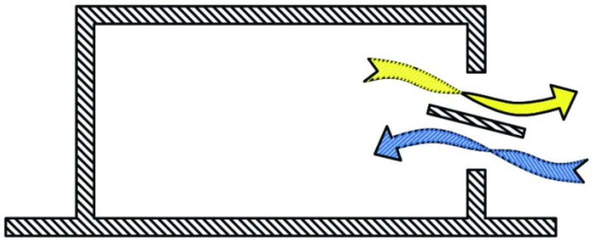


Figure 10: Single side ventilation

Cross Ventilation

In cross ventilation, air flows in from one opening and flows out from the opening on the opposite side of the space.

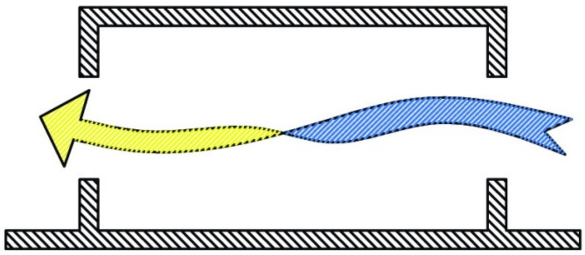


Figure 11: Cross ventilation

Stack Ventilation

Stack effect is the pressure difference between the confined hot gas in a chimney or stack and the cool outside air surrounding the outlet (Answers.com 05.04.2007). Stack ventilation requires lower and upper openings through which cool and warm air pass, respectively. The buoyancy force pushes air through the stack due to density variations between the upper and lower sections. “The stack effect or upward displacement ventilation, occurs where air enters at low level, is heated, and then vents from high level stacks atop the building” (Nottingham City Council 04.04.2007, p.9). When warm air rises to the roof of a building, a small vacuum is created at the lower level of the building, sucking in fresh ambient air through open windows there to create a natural airflow (Window Master 02.07.2007).

A solar chimney demonstrates effective stack ventilation. “Solar chimneys create a column of air at a higher temperature, which generates higher pressure differences and so enhances the stack effect. A passive stack can also be generated through an atrium, which will also act as a buffer to reduce heat losses” (Nottingham City Council 04.04.2007, p.9). To be effective, the stack effect requires a certain height difference between the windows used for air inlet and outlet (Window Master 02.07.2007), large openings, and not-so-deep floor plans (Nottingham City Council 04.04.2007, p.9).

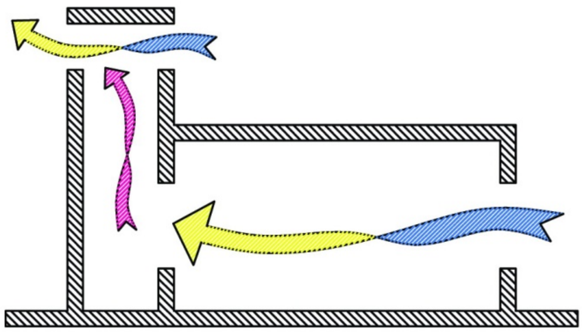


Figure 12: Stack ventilation

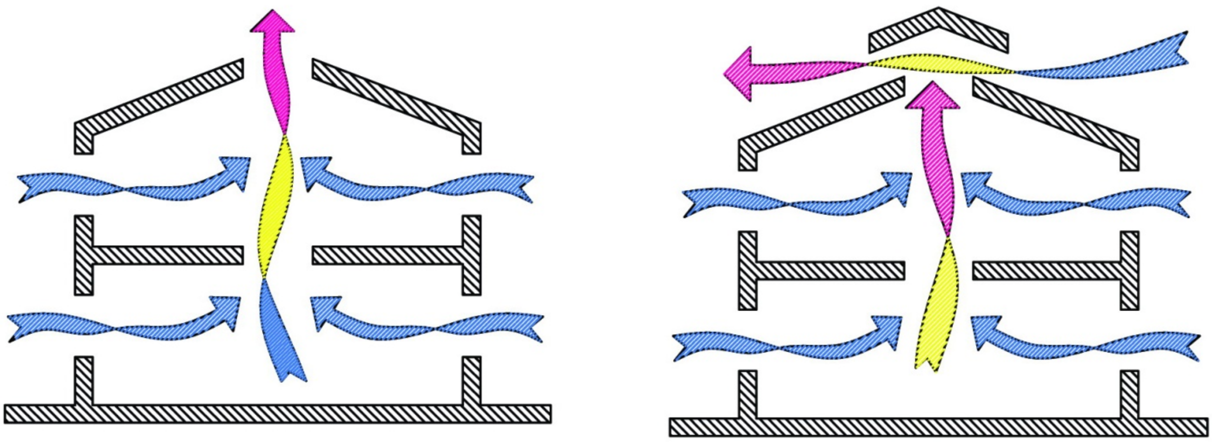


Figure 13-14: Stack ventilation

Wind Scope

In wind scope ventilation there is a tower that needs openings on each side controlled by louvers in order to exploit various wind directions (Cavelius et al. 05.04.2007). This may, however, negate the effects of stack ventilation with wind forces opposing the buoyancy forces.

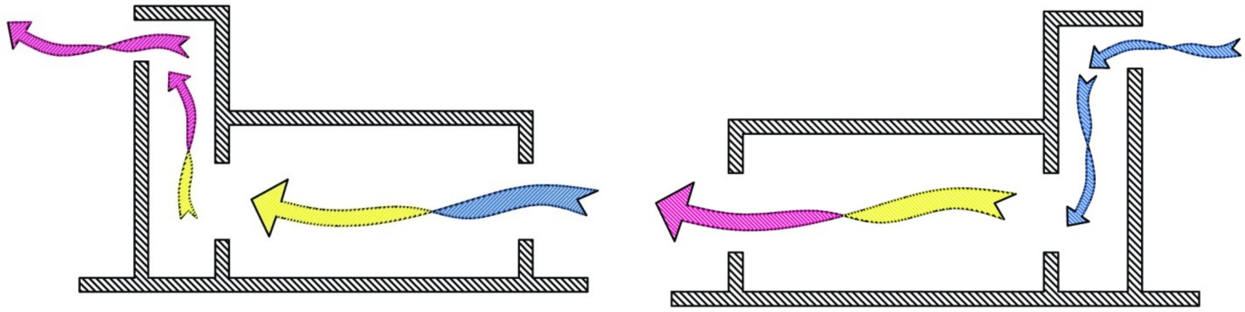


Figure 15-16: Ventilation with wind scope

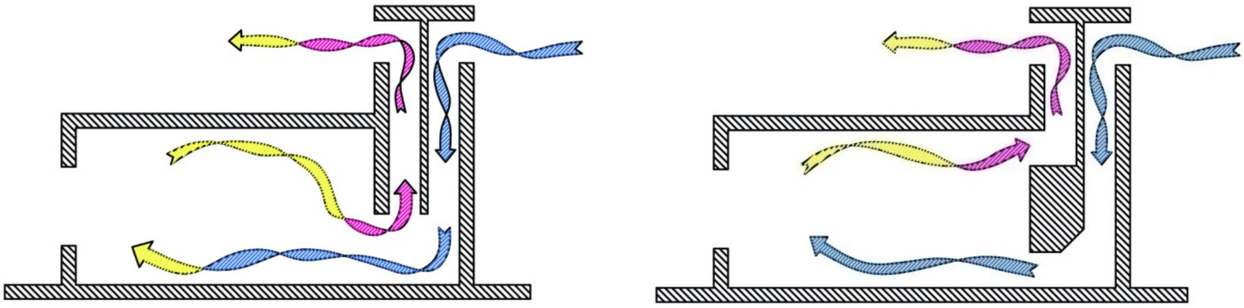


Figure 17-18: Ventilation with wind scope

Evaporative Cooling

Water

Water absorbs latent heat as it evaporates. This heat is drawn from the surrounding, thus causing it to cool. For this reason, water evaporation in an environment can be used as a passive cooling method. Evaporation rate and thus the cooling rate rises with an increase in the area of water surface exposed to air and air or water movement, and a decrease in air humidity (and pressure). An inverse relationship exists between relative humidity and amount of evaporation and the difference between wet-bulb and dry-bulb temperatures. Thus the cooling efficiency of evaporative cooling will be decreased in humid conditions. Therefore evaporative cooling is most effective in dry climates.

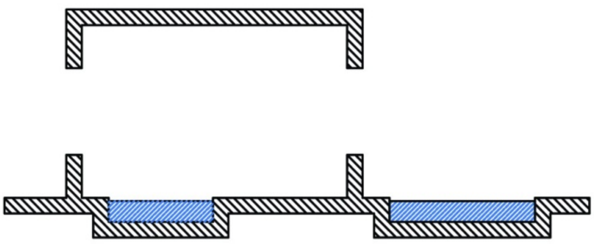


Figure 19: Evaporation cooling with water bodies

Iran's cold climatic region has a warm and dry summer climate and can therefore use evaporative cooling as a summer cooling strategy.

Vegetation

Vegetation evaporates the water absorbed by roots through their leaves and the latent heat used for this evaporation is drawn from its surroundings. Therefore vegetation, especially that which uses more water and has bigger leaves, has more evaporative cooling efficiency.

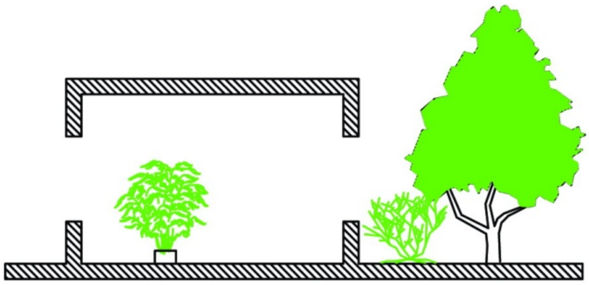


Figure 20: Evaporation cooling with vegetation

Water pools and ponds and also trees and plants can be used in courtyards to create a cool microclimate which also affects the condition of living spaces. They can even be used in rooms themselves.

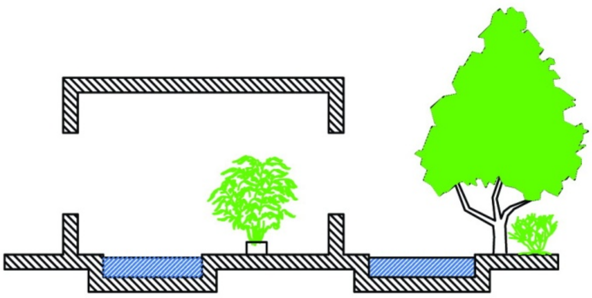


Figure 21: Evaporation cooling with water ponds and vegetation

Evaporative Cooling and Natural Ventilation

Natural Ventilation over Water Ponds and Vegetation

Increasing air movement increases evaporation and cooling efficiency. Therefore natural ventilation and evaporative cooling from water ponds and vegetation can be used together to increase cooling efficiency.

Natural ventilation can also be used to carry the air cooled by evaporation to internal spaces. Therefore evaporative cooling (via water pools, ponds and vegetation) can be done in an adjacent open environment or in front of windows, cool towers or vents, carrying the cooled air to the internal spaces via natural ventilation.

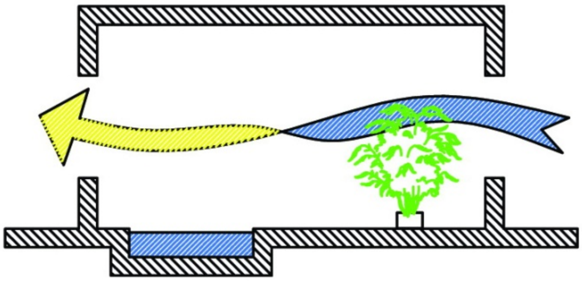


Figure 22: Internal evaporative cooling and natural ventilation

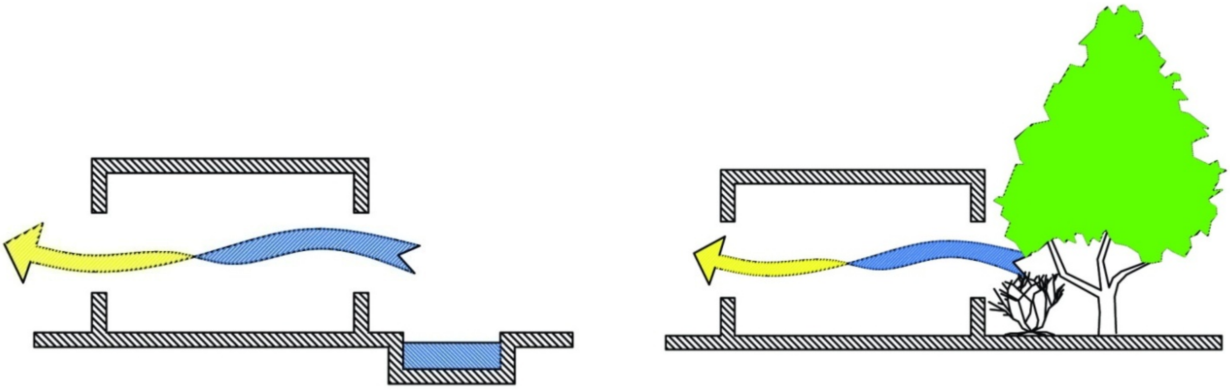


Figure 23-24: Outside evaporative cooling and natural ventilation

In this case, natural ventilation cools the spaces and the pre-cooled air entering the building increases the cooling efficiency.

Wind Tower with Water Pond

Wind towers are used to move wind from a higher level into the internal spaces of a building. If a water pond is used at the base of the wind tower, it causes not only the evaporative cooling to increase the efficiency of natural ventilation but also the air movement at the surface of the water to increase the evaporation. Thus, the cooling capability is increased.

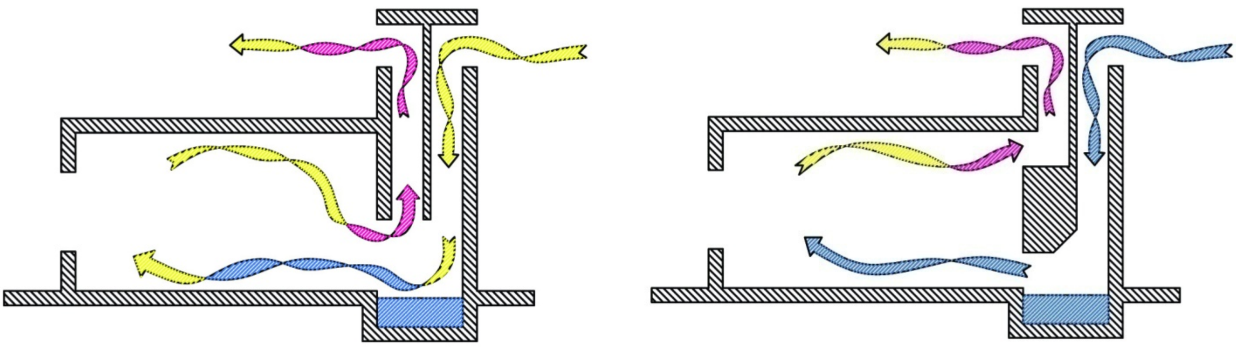


Figure 25-26: Wind tower with water pond

Earth Cooling and Natural Ventilation

During the summer months, the ground temperature is lower than the air temperature. Thus, the air that naturally passes through the underground vents or pipes to enter the building (with the buoyancy and stack effects, for example) has a rather a strong cooling effect.

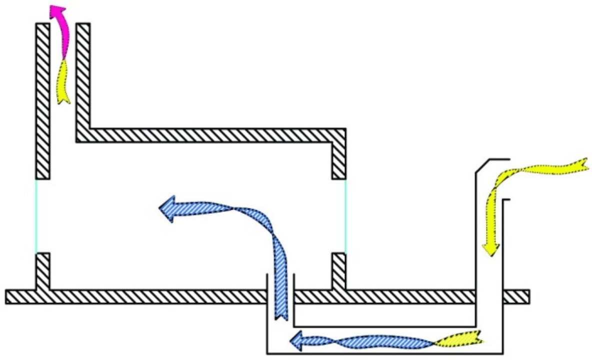


Figure 27: Earth cooling and natural ventilation

Earth Cooling, Natural Ventilation, and Evaporative Cooling

The process of passing the air through underground vents by natural ventilation has a high cooling efficiency. This is due to the cooling performance of natural ventilation, earth cooling, and also evaporative cooling (evaporating water from adjacent wet soil).

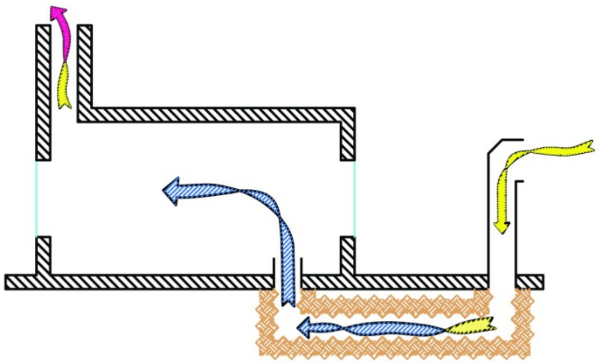


Figure 28: Earth cooling, natural ventilation and evaporative cooling (Underground open vents)

Green Roofs

Not only do green roofs have many ecological advantages, but they also cool efficiently by preventing solar radiation heat gain and by evaporation and cooling of the surrounding environment. They also reduce the day-night roof temperature difference and act as insulation material.

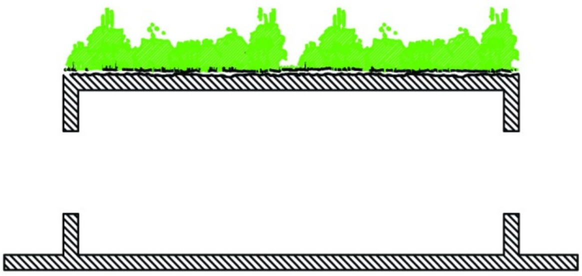


Figure 29: Green roof

Night Cooling

Night Structural Cooling (with Thermal Mass)

Nighttime air temperatures are significantly lower than daytime temperatures, especially in dry climates. By cooling building elements of high thermal mass (as well as water bodies, etc.) during the night, passive cooling can be achieved the following day.

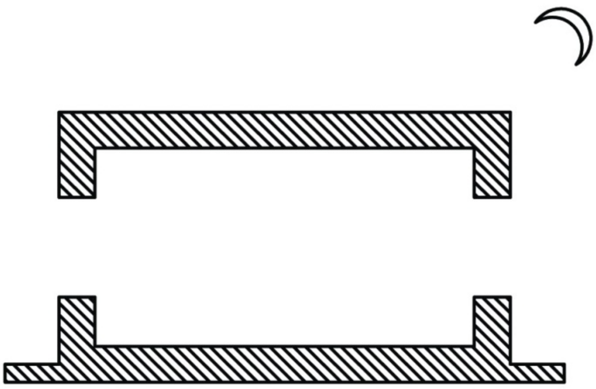


Figure 30: Night cooling with high thermal mass

Night Radiative Cooling

During the cooler hours of the night, because of the less sky temperature, heat can be radiated through glazed surfaces from the warmer internal surfaces to the sky, cooling the internal space. In night radiative cooling, the adjustable and movable shading devices must remain unused for the escape of long wave radiation not to be prevented. If night radiative cooling is desired, it is best to open the windows, as glass (especially Low-E glass) reflects longwave radiation, reducing the cooling efficiency.

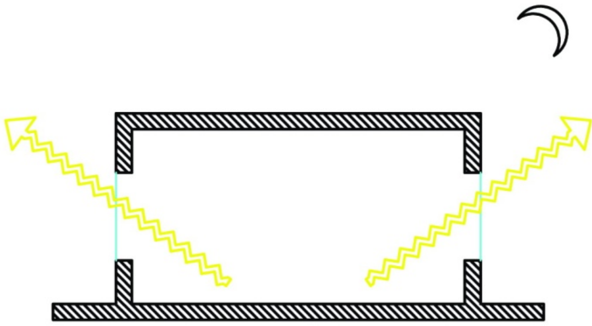


Figure 31: Night radiative cooling

Green Roofs, Evaporative Cooling and Natural Ventilation

Windward facing vents on green roofs for natural cooling purposes benefit from evaporative cooling (of water and vegetation), green roofing and natural ventilation. Advantages of this system include a high amount of evaporation, less energy demand for cool air movement to the internal spaces (due to the buoyancy effect), and space efficiency.

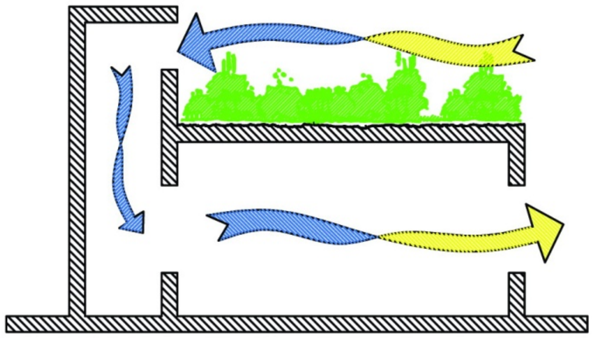


Figure 32: Green roof, evaporative cooling and natural ventilation

Natural Ventilation and Evaporative Cooling (Wind Towers, Windows and Vents with Wet Surfaces)

Locating a water saturated filter such as wet textile in front of a window, wind tower, or vent or locating water-saturated materials such as wet bricks or soil around a wind tower or vent increases the cooling efficiency of natural ventilation by evaporative cooling of the air that is to be circulated.

Hybrid Cooling

The following figure shows the various methods of hybrid cooling.

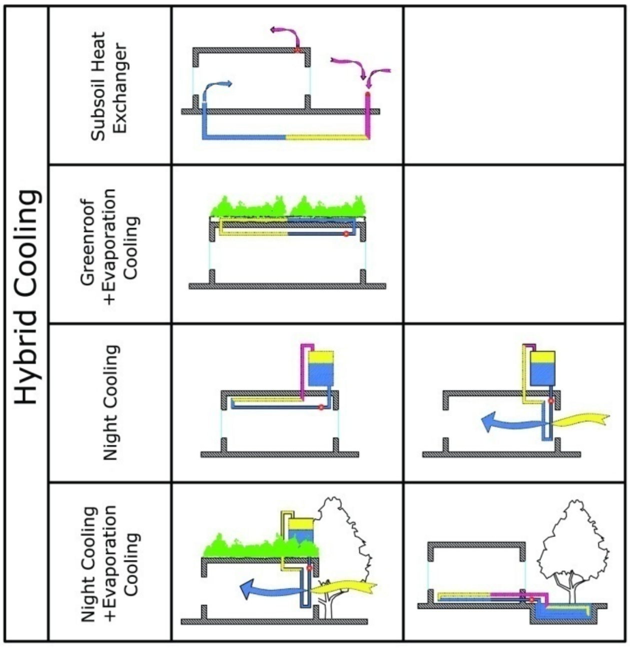


Figure 33: Different methods of hybrid cooling

Subsoil Heat Exchanger (Earth Cooling)

Mechanical (fan-assisted) earth cooling during the summer months can be used as a hybrid cooling method. If air in the underground pipes is passed over water or wet materials, or through open vents with wet muddy walls, its cooling efficiency is increased via evaporative cooling.

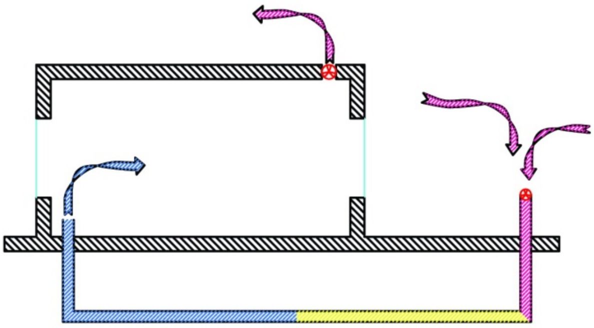


Figure 34: Subsoil heat exchanger

Night Cooling (with Storage of Night-Cooled Water)

A water tank, located outside the building and shaded during the day, can store the night-cooled water for cooling throughout the following day. Less energy is required to circulate the water if the tank is located on the roof. This is due to the buoyancy effect, in that cool water easily falls to the internal spaces and warm water rises to the tank.

The cool water is carried to the internal spaces during the day (when the water temperature is less than that of the internal air) by an automated pump and return to the tank after absorbing heat from the air.

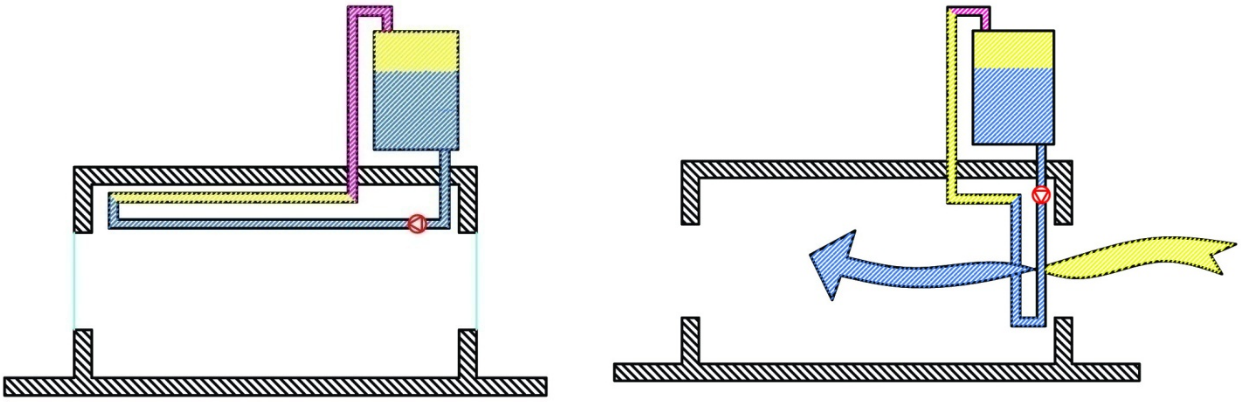


Figure 35-36: Cooling with night cooled water storage

Green Roof and Evaporative Cooling

Evaporation through vegetation and wet soil on a green roof and shading from vegetation will decrease the temperature of wet soil. This can be used for cooling the building by circulating cooled water in and out of the building.

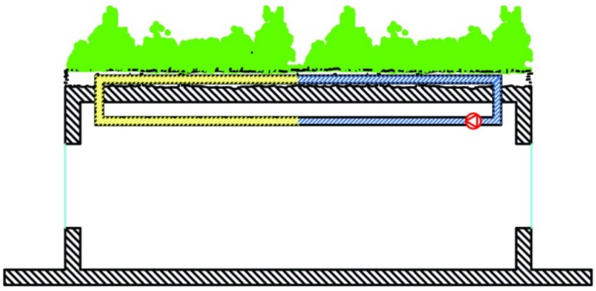


Figure 37: Hybrid cooling with green roof and evaporative cooling

Night Cooling and Evaporative Cooling

If green roofs are combined with rooftop water tanks for night cooling, the vegetation and wet surfaces around the tank further cool the water within (during both day and night). This combination of the advantages of both systems results in high system efficiency. The cool water can be carried by a pump from storage to the spaces, when needed.

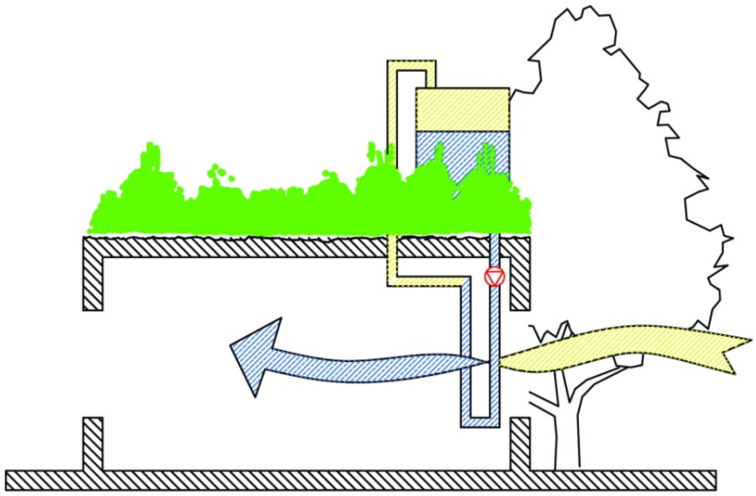


Figure 38: Night cooling and evaporative cooling

The water in courtyard ponds cools via both the low air temperature during the night and the evaporation during both day and night. If a water-circulating pipe passes through such as pond to living spaces, it causes these spaces get cooler. Pumps can automatically begin circulation once the water temperature drops below that of the internal air.

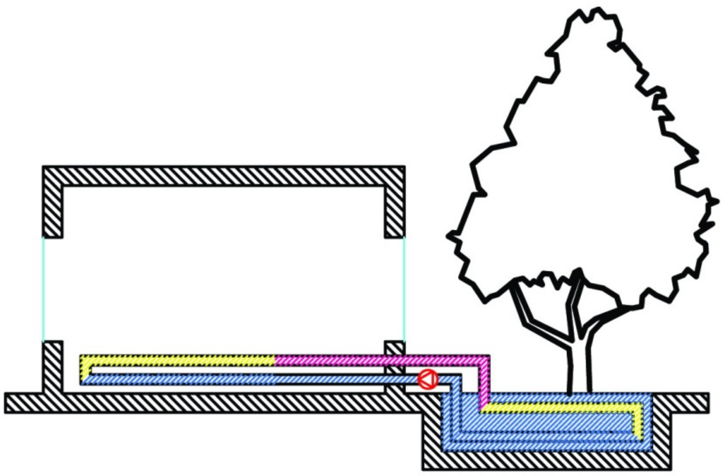


Figure 39: Night cooling and evaporative cooling

Chapter Two: Iran

State of Knowledge

Recognising the importance of reducing worldwide primary energy consumption, in 1995 Iran founded various governmental organizations to research energy conservation and renewable energies, the most notable of which are the “Iranian Fuel Conservation Organization” (IFCO), the “Iran Energy Efficiency Organization” (IEEO), and the “Renewable Energy Organization of Iran” (SUNA).

Iranian Fuel Conservation Organization (IFCO)

The “National Iranian Oil Company” (NIOC) established the “Iranian Fuel Conservation Organization” (IFCO) in 2000 as a subsidiary branch with the mission to regiment the fuel consumption in different sectors through review and survey of the current trend of consumption, and to execute nationwide conservation measures. IFCO is contemplating introducing a modern energy management reformation to all of Iran’s economic subsystems in order to achieve all conservation goals for the all energy carriers defined in the country’s sustainable energy program.

The IFCO’s goals for fuel conservation in Iran are to:

- Enhance public awareness by publishing books, magazines and advertising campaigns
- Provide comprehensive energy conservation programs for transportation systems
- Enforce fuel conservation measures in the building sector
- Produce high quality and efficient home appliances and fuel consuming systems
- Implement industrial energy conservation
- Provide disciplinary measures to support the public conservation culture
- Technically and financially assist research institutes and universities to hold energy management training courses for government and private sectors

The energy conservation policies of this organisation focus on wise energy consumption and cooperation in the reduction of greenhouse gas emission.

The IFCO uses the three methods of rule making (regulations, rules and standards, and practical systems), support (tax exemption, subsidisation, and technological improvement), and information (labelling, education, advertisement) (Iranian fuel conservation organization 12.03.2008) .

Iran Energy Efficiency Organization (IEEO)

The Iran Energy Efficiency Organization, established in 1995, administers the plans of Energy Affairs deputy of Ministry of Energy to promote a culture of energy conservation and productivity, and to encourage participation from the private sector.

The IEEO is now well prepared to service the industry, researchers, and academics. It has a record of energy auditing in factories in various industries, a collection of measuring instruments, experienced staff, modern laboratories for the formulation of energy consumption standards (for household appliances and industrial elements), a collection of information, books, and professional publications related to energy management, and it organises national and international seminars and training courses (Iran Energy Efficiency Organization 18.05.2008).

Renewable Energy Organization of Iran (SUNA)

In 2000, the energy deputy of the Iranian Ministry of Energy established the Renewable Energy Organization of Iran (SUNA) with the mission to investigate and promote the use of renewable energies over primary energies. This organisation is divided into the sub-organisations of solar, biomass, geothermal, and wind energy (Renewable Energy Organization of Iran 18.05.2008).

Literature Analysis

The writing and translation of books on climate and architecture, climatic design, and the use of insulation material in buildings in Iran dates back to the late eighties. Most of these books were written around 1990. Since then, some further work has been done in this field; however, the past few years have seen a significant increase in literature on the subject (focussing on renewable energy, energy management, and energy conservation). The significance of this topic is becoming increasingly recognised in Iran.

In recent years, the above mentioned organisations have published many books on energy conservation and renewable energies (solar, wind, hydrogen and geothermal energies) with an emphasis on industry. The books on energy saving in architecture mostly focus on construction materials.

Also, several Master and PhD theses about energy saving in buildings have recently been written, all of which stress the effect of construction materials (such as insulation, windows, etc.) on a building's energy demand, and some of which discuss passive solar heating systems.

Building Energy Regulations

Iran has few regulations for the energy consumption in terms of how much energy can be used for a certain unit of surface. There are certain rules only for the U-factor levels of thermal envelope components. Although these rules can reduce the building energy consumption, they are rarely used by private buildings and do not lead to any significant reduction.

Practical Experiences

The Iranian organisations have, in recent years, built some energy efficient buildings and one zero-energy building. They are only as samples. These buildings are, however, expensive due to their reliance on construction materials with high heat conductivity resistance and the use of active solar systems. Also, financially speaking it would take many years for the savings gained from energy reduction to offset the excessive construction costs. Such buildings therefore remain only as example buildings.

Result

In Iran, they are recently giving more heed to saving energy, though only with a focus on industry rather than on energy conservation in buildings. For saving energy in buildings, often only heating and cooling systems and household appliances are studied, as well as the construction elements in buildings. For construction elements, the concentration is mainly on windows, insulation materials and air change, all of which is supported by the IFCO and BHRC organisations. There is generally no attention given to the reduction of energy consumption of buildings through architectural design.

There are many books written in Iran about climate, natural cooling, heating and cooling systems, and building elements (e.g. wall, window, insulation material) but no research or book exists that studies and analyses all of these factors in relation to each other, especially not leading to a practical and usable result or an energy-efficient building system. Nor does any book exist (written or translated) that discusses passive houses.

To achieve a practical result in such fields as energy efficient architectural style and neighbourhood typology, it is therefore necessary to study the factors like climate, energy, and architecture together and in connection with each other.

Climate

Climatic Zones

General Climatic Regions

This research paper focuses on Iran; however, the country has several different climatic regions, one of which must be chosen as the research area. There are many systems for classifying climate zones, but W. Köppen's is the most widely accepted (Olgyay 1963, p.6). According to Köppen classification, Iran has been divided into four different climatic regions. These regions are:

1) Cold
2) Temperate and humid
3) Warm and humid
4) Warm and dry (Kasmaei 2004, p.83)

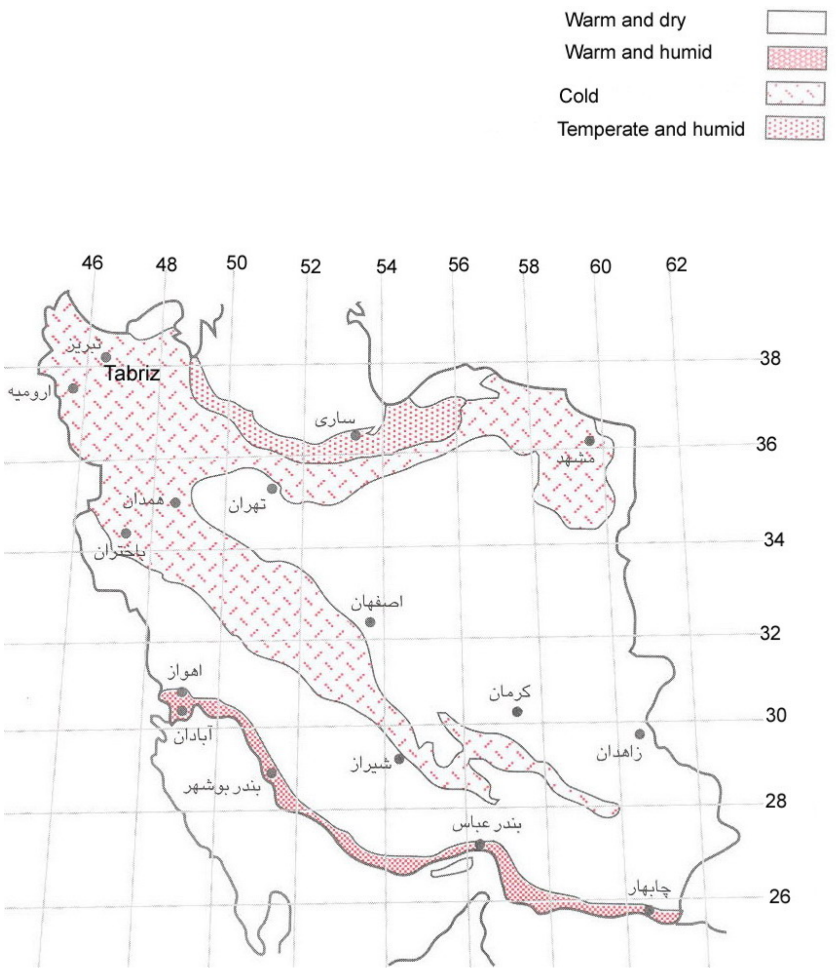


Figure 40: Climatic regions of Iran according to Köppen classification, Source: Kasmaei 2004, p.83 (my modifications)

Winter and Summer Climatic Regions

According to Olgyay's bioclimatic chart, Iran is divided into 6 winter climatic regions and 5 summer climatic regions.

The winter climates are:

1. Very cold
2. Cold
3. Temperate and humid
4. Temperate and dry
5. Warm
6. Warm and humid (Kasmaei 2004, p.98)

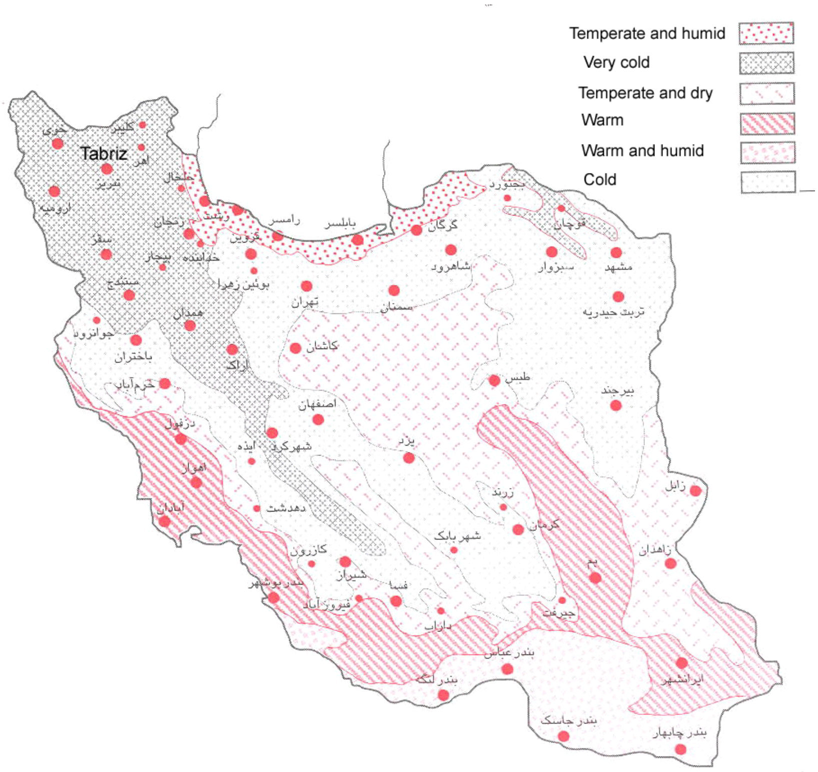


Figure 41: Winter climatic regions of Iran, Source: Kasmaei 2004, p.98 (my modifications)

The summer climatic regions of Iran are:

1. Temperate and humid
2. Warm and dry
3. Very warm and dry
4. Warm and humid
5. Very warm and humid (Kasmaei 2004, p.98)

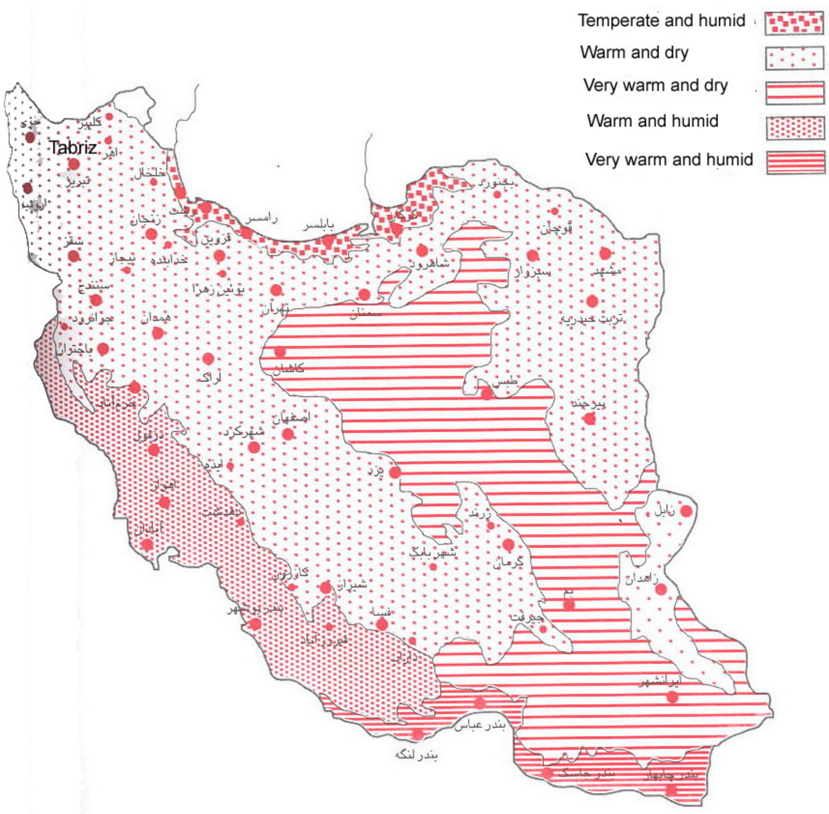


Figure 42: Summer climatic regions of Iran, Source: Kasmaei 2004, p.98 (my modifications)

Cold Climatic Zone

The research area is the cold climatic region of Iran which, from a geographical viewpoint, is a mountainous region. According to Olgayay's bioclimatic chart this region has a very cold winter climate and a warm and dry summer climate. The average of minimum and maximum temperatures and the large cities located in this region are shown in the following table:

Table 7: The average of minimum and maximum temperature and the large cities of the very cold climatic region of Iran, Source: Kasmaei 2004, p.99

Climate in winter and summer	Average of Min temperature in winter (°C)	Average of Max temperature in summer (°C)	Cities
Very cold winter Warm and dry summer	-5 - -10	35 - 40	Tabriz, Zanjan, Oroomieh, Sanandaj, Hamedan, Arak, Ardebil, Shahrekord, Kermanshah

Climate of the City of Tabriz

Based on Köppen's classification, the city of Tabriz has "BSk" climate type and a mid-latitude, dry, semi-arid climate. On the basis of ASHRAE Standards (90.1-2004 and 90.2-2004 Climate Zone), this city has "3C" climate type with a Warm – Marine and Dry Summer Subtropical (Mediterranean) climate. The latitude, longitude, elevation, annual heating and cooling degree days of Tabriz are as follows:

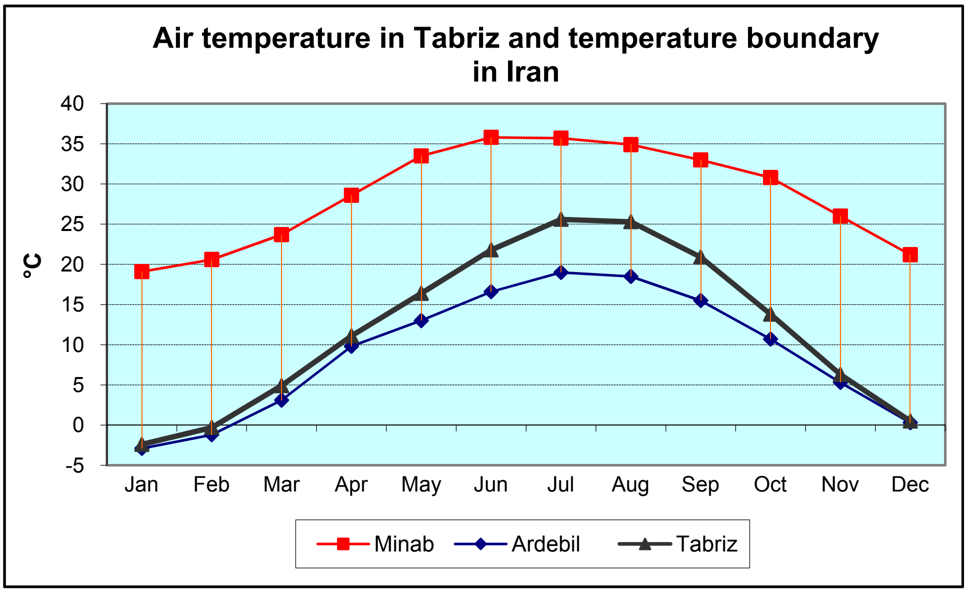
Table 8: General geographical information of Tabriz, Source: Based on data from Iran Meteorological Organization 12.03.2008

Latitude	Longitude	Elevation	Heating degree day	Cooling degree day
38 5 N	46 17 E	1361.0 M	2773.2	392.9

Climatic Parameters of Tabriz (Climatic Data)

Air Temperature

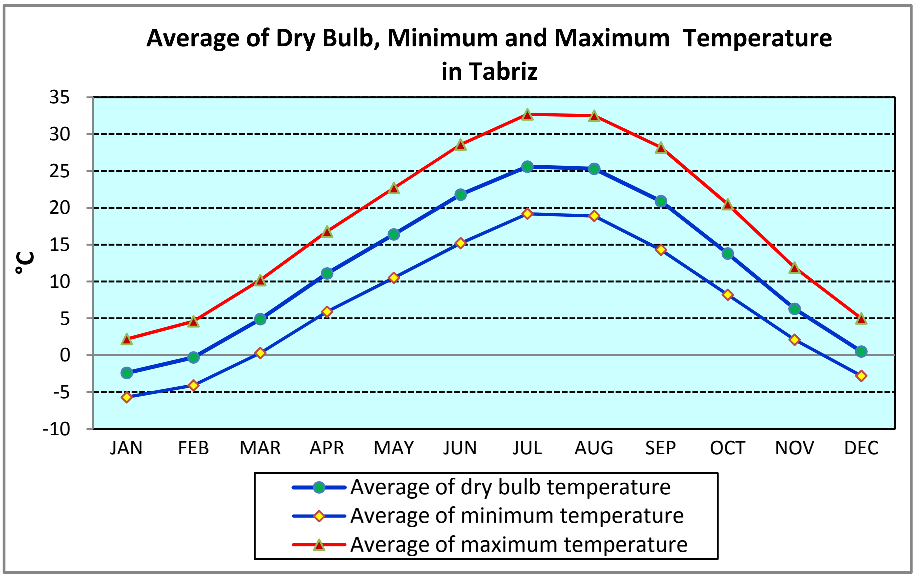
Based on annual average temperature, the warmest city of Iran is Minab and the coldest city is Ardebil[1] (Iran Meteorological Organization 07.01.2008). The following graph shows the average dry-bulb temperature of the coldest and warmest cities of Iran as Iran's temperature boundary. It also represents the air temperature of Tabriz. Based on the following graph, Tabriz has a cold winter and warm summer compared to other cities of Iran.



Source: Based on data from Iran Meteorological Organization 07.01.2008

The average air temperature of Tabriz differs from -2.4 to 25.6°C from January to July. The average maximum temperatures for these two months are 2.2 and 32.7 respectively and the average minimum temperature varies from -5.7 to 19.2°C.

1 - The annual average temperature of Minab is 28.6 and Ardebil is 9 °C (Iran Meteorological Organization, 07.01.2008).



Source: Based on data from Iran Meteorological Organization 07.01.2008

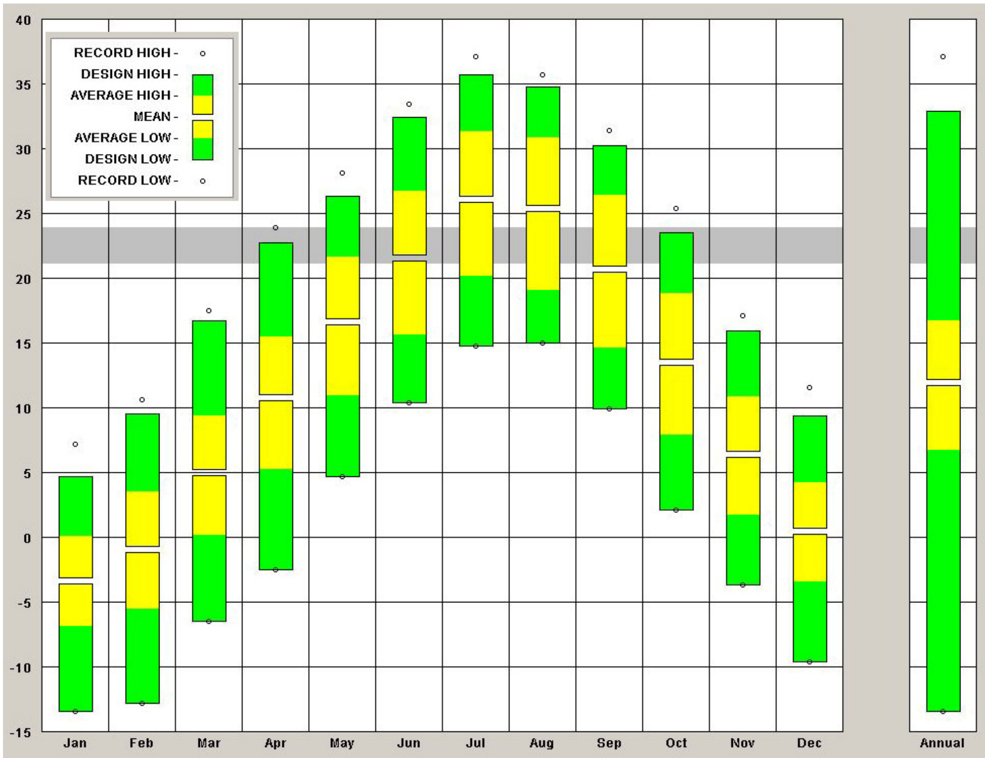
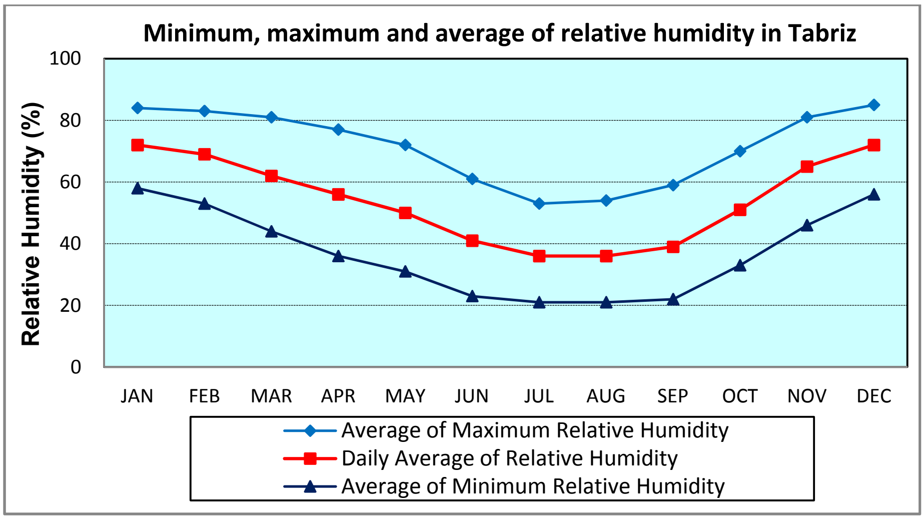


Figure 43: Temperature range in Tabriz, Source of Weather Data: U.S. Department of Energy.01.2008b

Air Humidity

Tabriz has a maximum monthly average relative humidity in January with 72% and the minimum in July with 32%. The following table shows the monthly average relative humidity in Tabriz.



Source of Weather Data: U.S. Department of Energy 14.01.2008b

The following figure shows the dry bulb temperatures and relative humidity of Tabriz for different months.

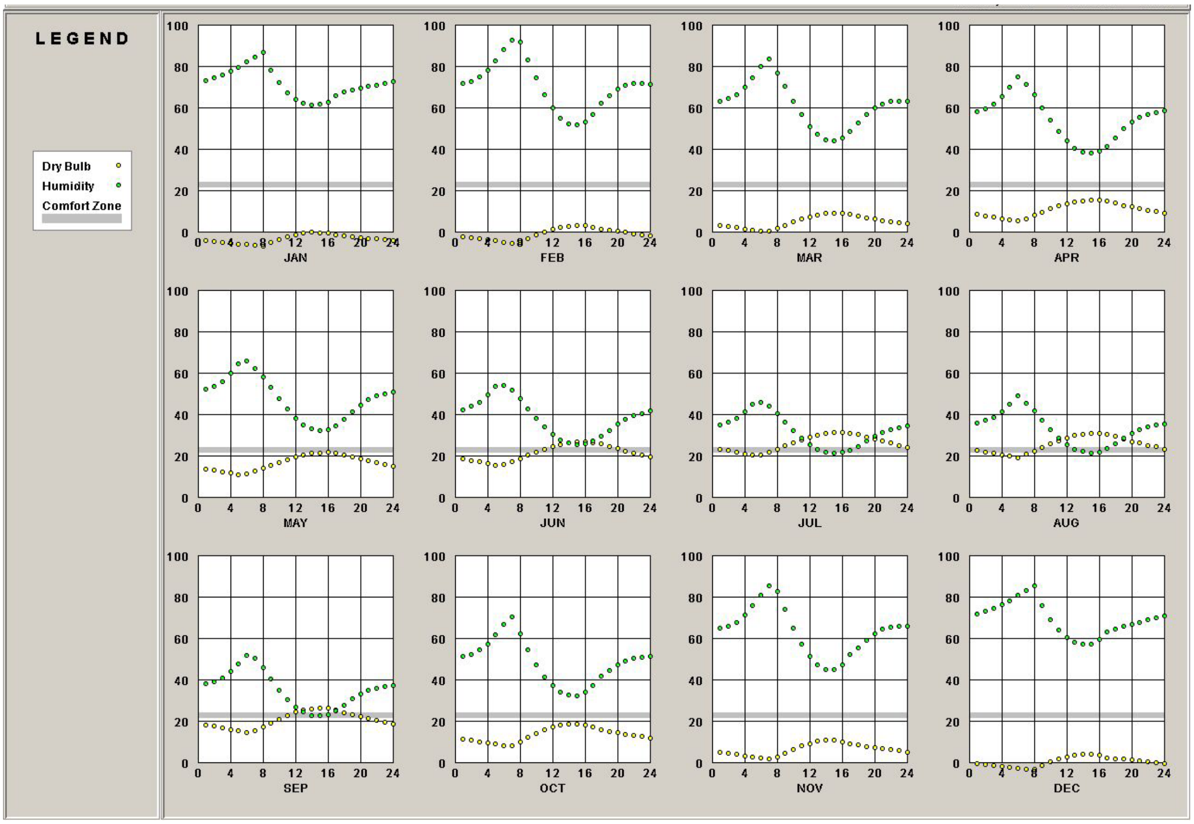


Figure 44: Dry bulb temperature and relative humidity of Tabriz in different months, Source of Weather Data: U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

Solar Radiation

The amount of solar radiation received in Iran differs according to factors such as climate, latitude, elevation etc. The annual average daily solar radiation in different regions of Iran varies from 2.8 to 5.4kWh/m² and in the research area (very cold climatic region) differs from 3.8 to 5.4kWh/m². The city of Tabriz (and nearby areas) has a daily solar radiation varying from 3.8 to 4.5kWh/m² (Iranian fuel conservation organization 2005b, p.1). The average daily solar radiation in Iran differs from 4500 to 5750kWh/m²day and it is approximately 5250 kWh/m² in areas around Tabriz.

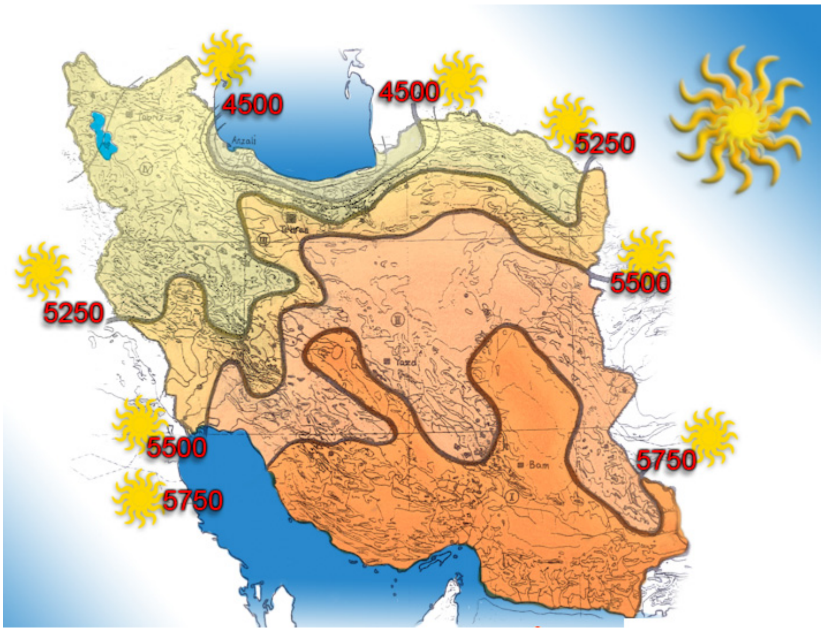


Figure 45: The average of daily solar radiation in Iran (kWh/m²day), Source: Iranian Fuel Conservation Organization, 2005

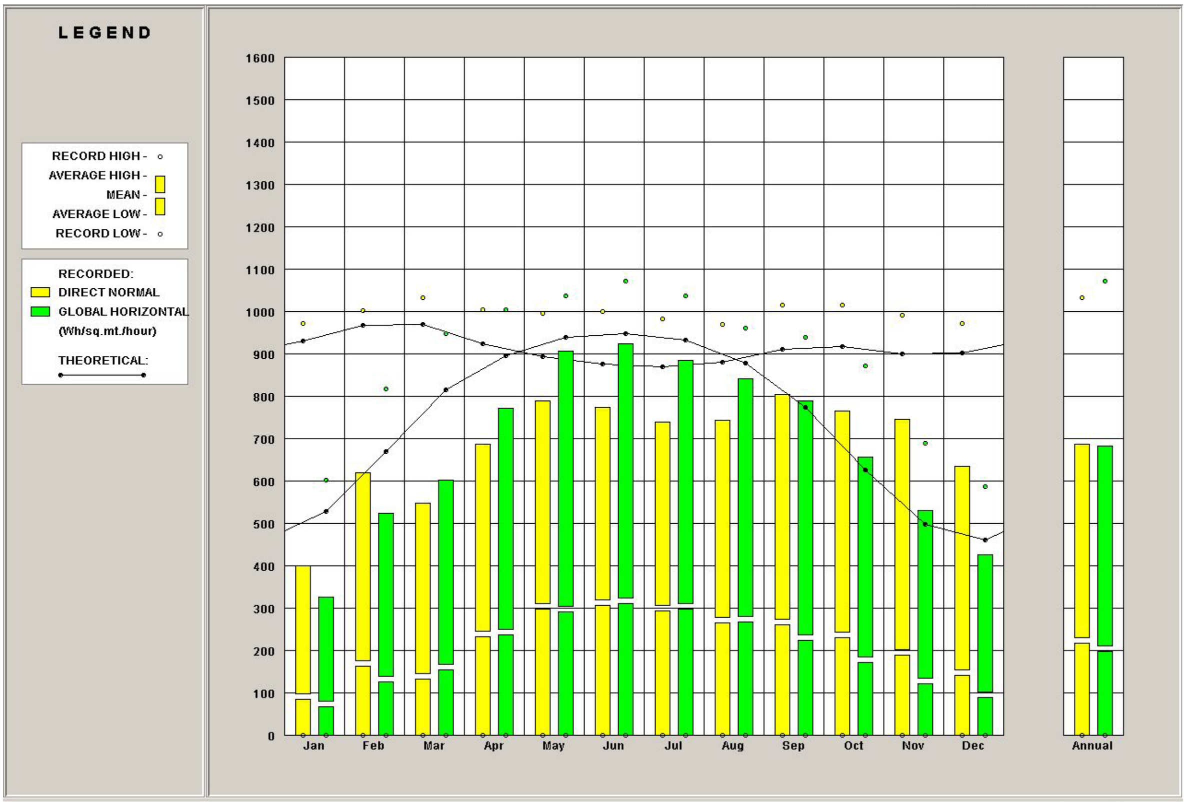
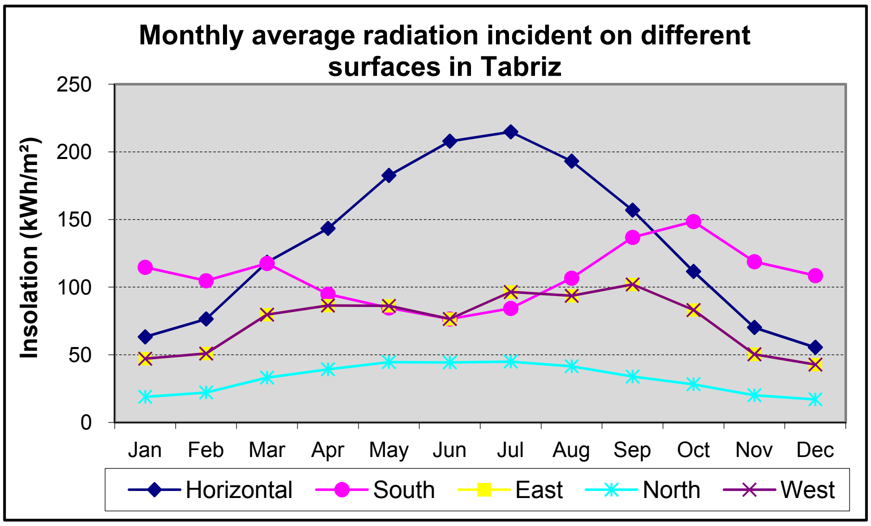


Figure 46: Radiation range in Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

The direct, diffused, and global yearly averages of solar radiation for Tabriz are 64189, 20572 and 84761Wh/m² respectively and the city has 2777.7 hours of sunshine a year. The following figure shows the radiation range (record high, average high, minimum, average low and record low radiation) in Tabriz.

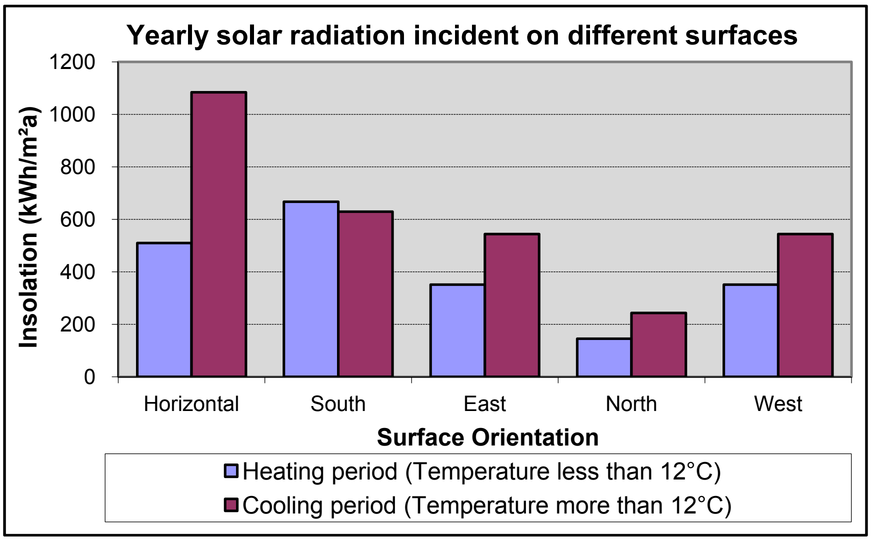
Orientation and Solar Radiation

The following diagram shows the amount of insolation received at surfaces with different orientations during different months in Tabriz. It also shows that only south-facing surfaces receive more solar energy in cold months, when it is needed, than in warm months.



Source: Based on data from NASA 27.07.2006

The following diagram shows that, in Tabriz, the insolation incident on horizontal surfaces in cooling period is much more than in heating period. The same relationship applies for west and east-facing surfaces but with a smaller seasonal variation. For south-facing surfaces the amount of insolation in heating periods is more than in cooling periods and is also greater than the insolation received by horizontal, north, west and east-facing surfaces in heating periods.

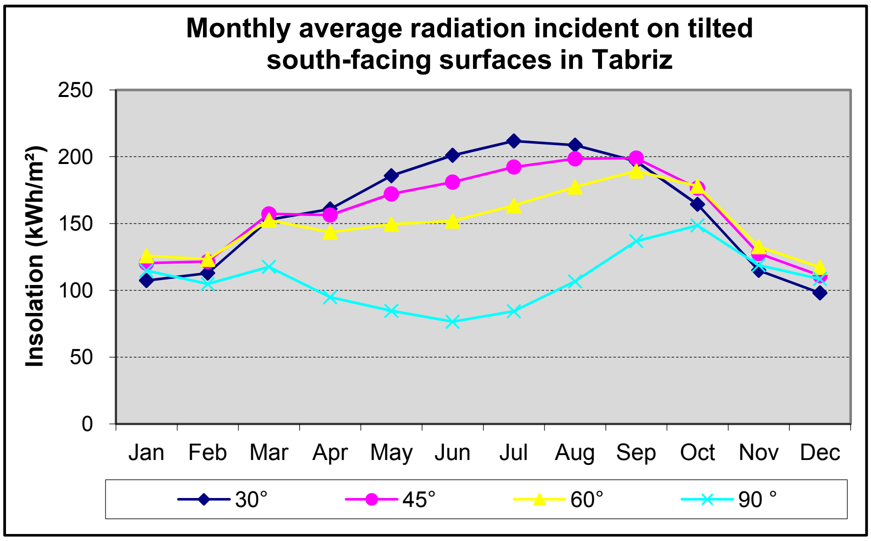


Source: Based on data from NASA 27.07.2006

These two diagrams show that, in order to maximise solar energy in heating periods (when it is most needed) and minimise in cooling periods, the main wall of the building plus the majority of windows in Tabriz must face south.

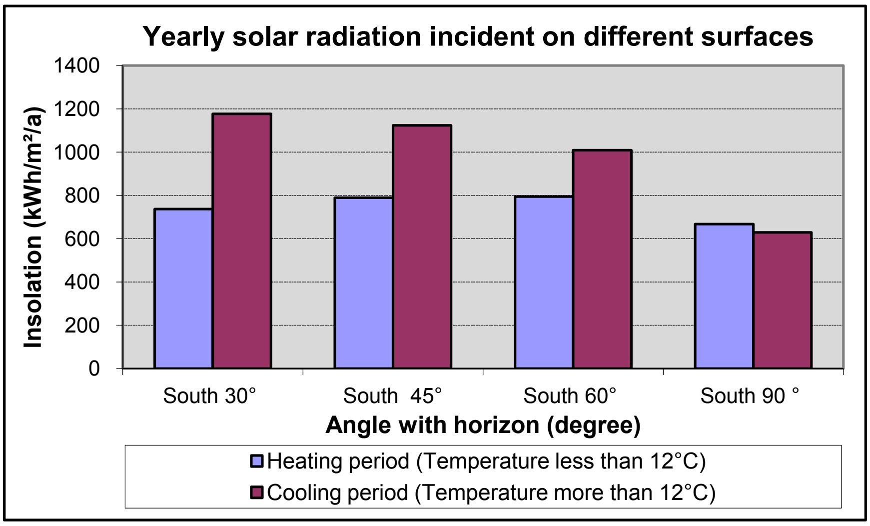
Solar Radiation Incident for Tilted South-Facing Surfaces

The following diagram shows the amount of solar radiation striking various tilted south-facing surfaces throughout the year. It demonstrates that the amount of insolation received by south-facing surfaces at 45 and 60 degree angles is slightly more during cold months and much more during warm months than vertical south-facing surfaces.



Source: Based on data from NASA 27.07.2006

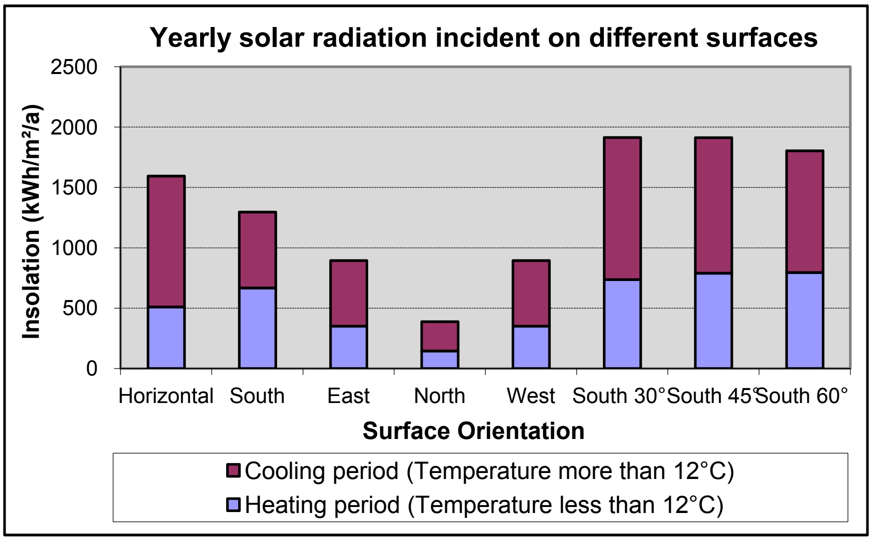
The amount of insolation received by 30, 45 and 60 degree south-facing surfaces during the heating periods is greater than that of vertical south-facing surfaces. In the cooling period too, the tilted surfaces of this kind receive more inlsolation than the verticals. On the other hand, the tilted surfaces receive more insulation in summer than in winter. Therefore the use of passive solar energy is best combined with vertical south-facing windows, or tilted south-facing windows if effective external movable shading devices are used.



Source: Based on data from NASA 27.07.2006

Orientation and Solar Radiation in Heating and Cooling Periods

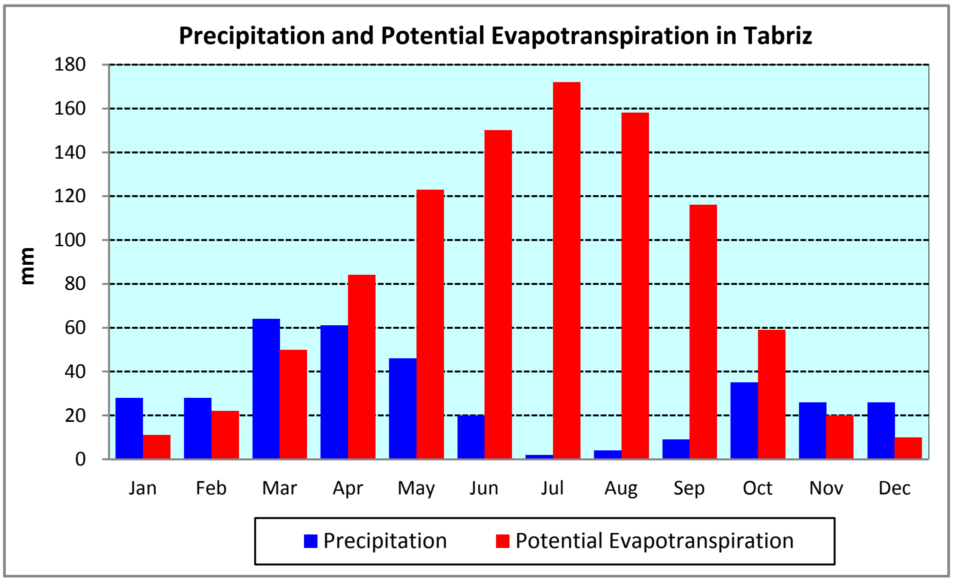
The following diagram compares the total amount of solar radiation received by vertical surfaces at varying orientations and tilted south-facing surfaces at varying angles. It shows that south-facing surfaces, especially those tilted at 45 and 60 degree angles, receive more energy throughout the year. They are very suitable for active solar systems and/or passive solar systems (such as windows) with summer control during cooling periods.



Source: Based on data from NASA 27.07.2006

Precipitation

Most of Iran's cities have little precipitation, especially those in dry climatic regions. Tabriz receives an annual average of 293.3mm of precipitation (Iran Meteorological Organization 12.03.2008). The following graph shows the monthly average precipitation and potential evapotranspiration for Tabriz. The high potential evapotranspiration for summer in Tabriz means that evaporative cooling can be used in this city as a passive cooling method.



Source: Based on data from Food and Agriculture Organization of United Nations 11.09.2007

Wind

The following figure, a wind wheel for Tabriz, shows the windy hours, the wind direction, wind speeds (maximum, minimum and average), wind temperature, and the relative humidity of wind. It shows that the annual maximum wind speed in Tabriz is about 16m/s and the annual average is between 3 and 4m/s in all directions. The annual average of relative humidity of wind is between 30 and 70%, and the air temperature is between 0 and 21°C in all directions. The wind blows most strongly from the northwest to the southeast and vice versa.

The wind temperature in January (the coldest month) is less than 0°C and the relative humidity is more than 50%. Throughout January, the wind mostly blows from the northwest, south, and southwest. The wind temperature in July (the warmest month) is between 21 and 24°C and the relative humidity is less than 40%. Throughout July, the wind mostly blows from the north, northwest and southwest (Source of Weather Data: U.S. Department of Energy 14.01.2008b).

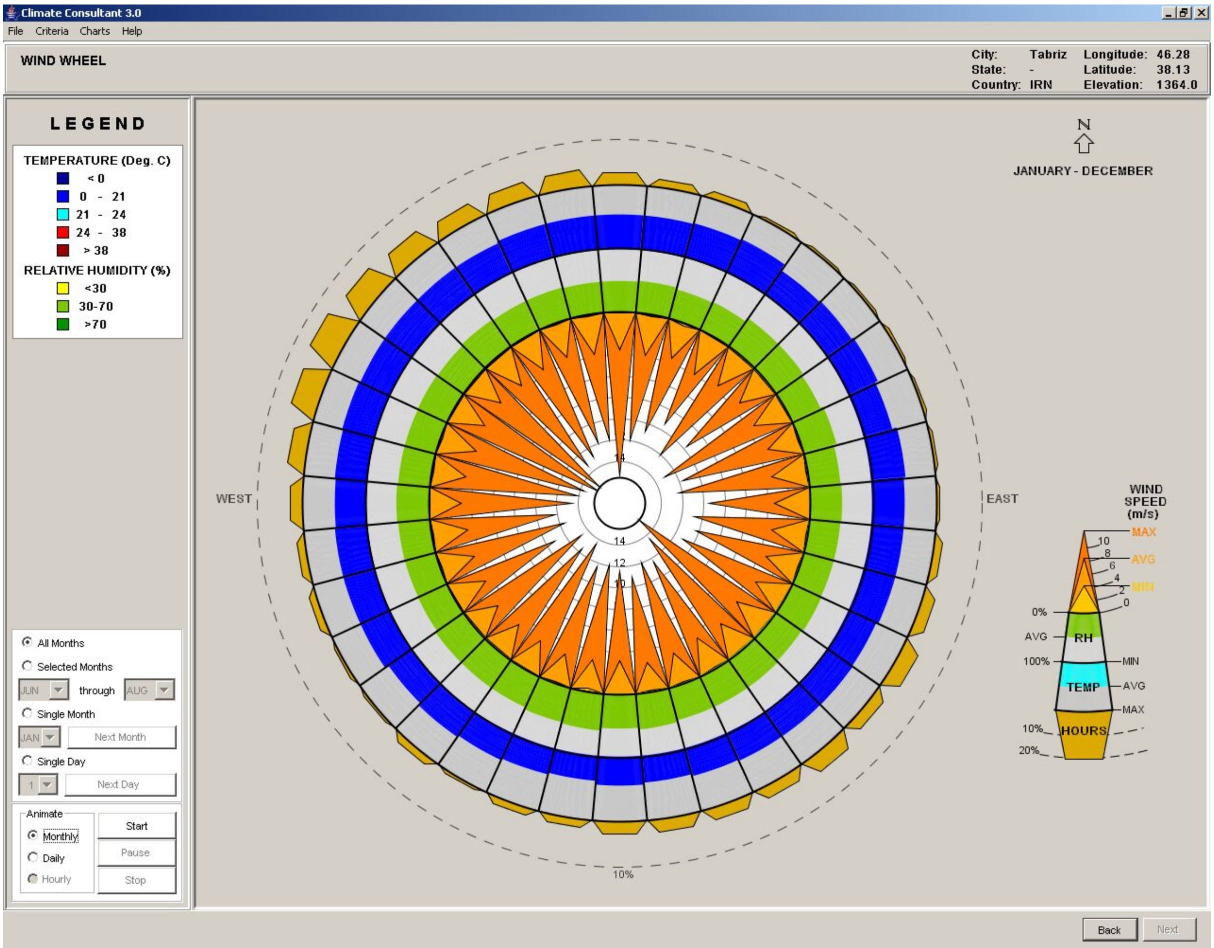
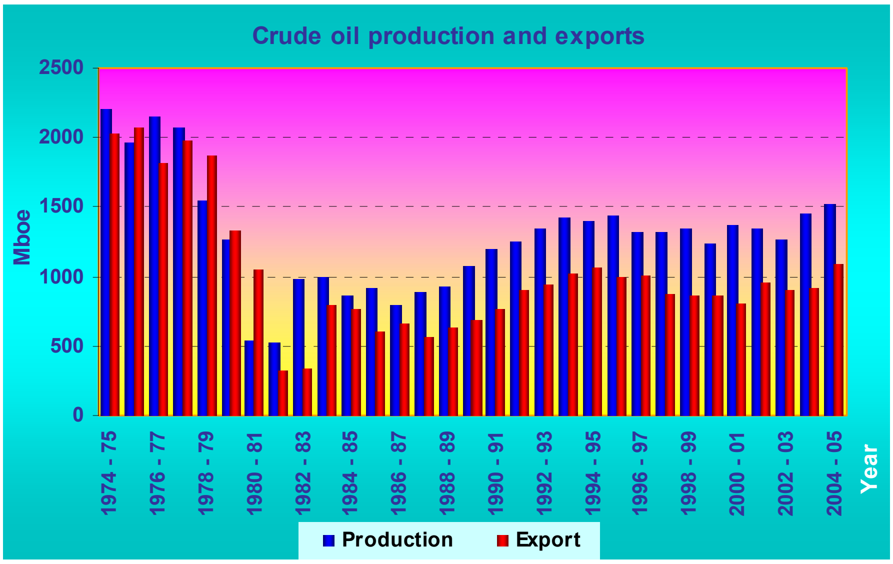


Figure 47: Wind wheel of Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

Energy

Iran has fossil energy sources and is the world's fourth largest oil producer (Tata et al. 2007, p.14). Although it produces and exports oil, the strong growth in domestic consumption and a slow expansion of refining capacity (Tata et al. 2007, p.14) have made it necessary to import some energy carriers such as gasoline. The following graph shows crude oil production and export data from 1974 to 2004.



Source: Iran Ministry of Energy 2006b

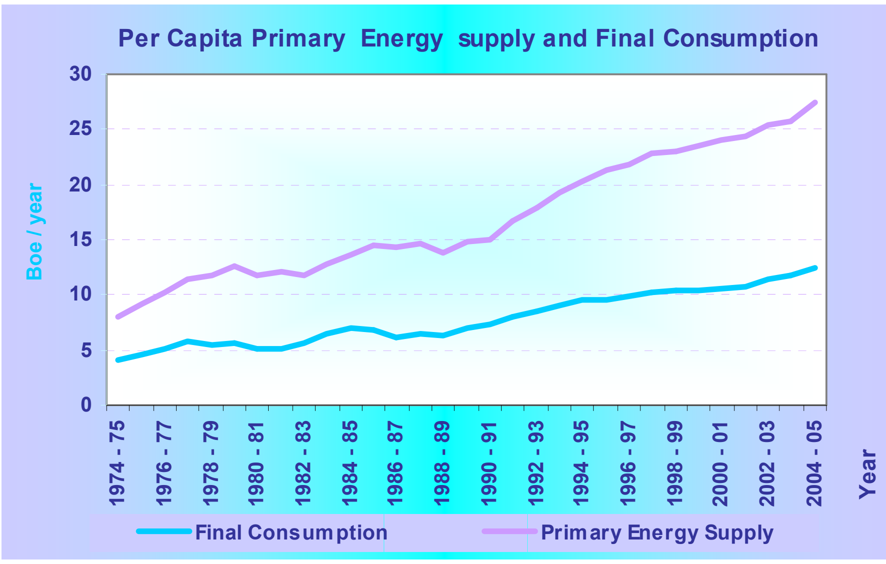
The following table shows the general energy and economic data in Iran from 1990 to 2005[1].

Table 9: General energy and economic data per capita indices, Source: Iran Ministry of Energy 2006b and Iran Ministry of Energy 2006, pp.31-33

Year	1990 - 91	1991 - 92	1992 - 93	1993 - 94	1994 - 95	1995 - 96	1996 - 97	1997 - 98	1998 - 99	1999 - 00	2000 - 01	2001 - 02	2002 - 03	2003 - 04	2004 - 05
Primary Energy Supply (BOE)	9.33	10.23	10.81	11.67	12.08	12.60	12.65	13.10	13.44	13.71	13.98	14.05	15.01	15.63	16.56
Final Energy Consumption (BOE)	6.60	7.16	7.70	7.97	8.63	8.76	8.72	9.05	8.97	9.32	9.74	9.89	10.53	10.79	11.5
Electricity Generation (kWh)	1084.78	1148.45	1201.11	1308.02	1383.45	1436.75	1513.12	1604.48	1673.22	1795.73	1906.60	2017.69	2152.59	2296.99	2473.66
GDP at constant 1997 prices (1000 Rials)	4011.14	4388.42	4473.47	4449.90	4383.14	4522.90	4725.74	4788.08	4854.27	4860.71	5027.48	5122.80	5424.97	5669.94	5901.73

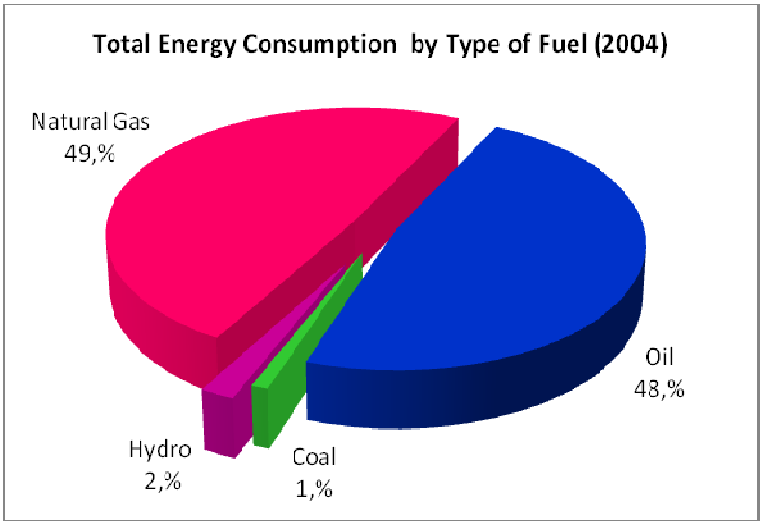
[1] - New Year of Iran is started from 21 March every year until 20 March next year.

The following graph shows the energy supply and final consumption per capita. An increase in both primary energy supply and final consumption can be seen from 1974 to 2004. Iran's final consumption per capita is 12.51Boe/year.



Source: Iran Ministry of Energy 2006b

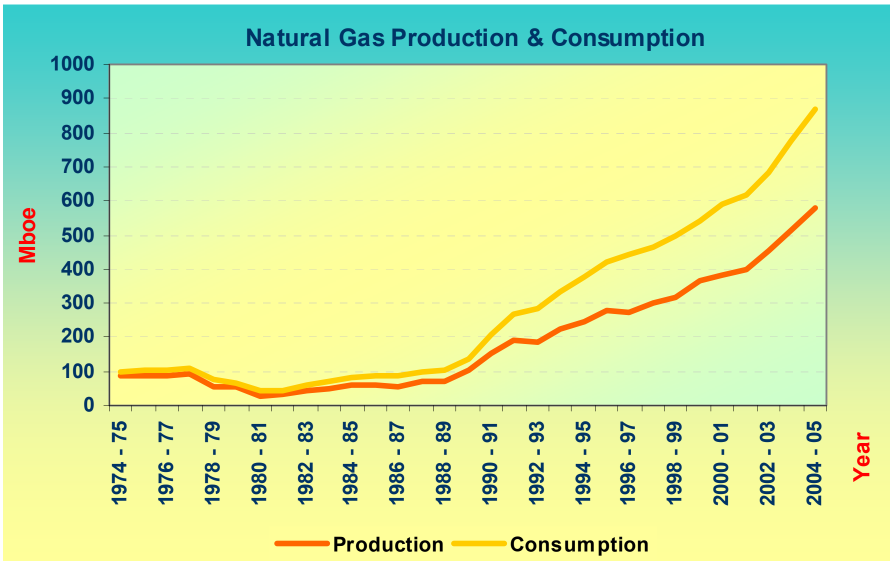
The following graph represents Iran's total primary energy consumption by type of fuel in 2004. 97% of Iran's energy consumption belongs to oil and natural gas, with only about 3% belonging to other energy sources such as hydro power, coal, etc.



Source: Energy Information Administration 2008a, p.1

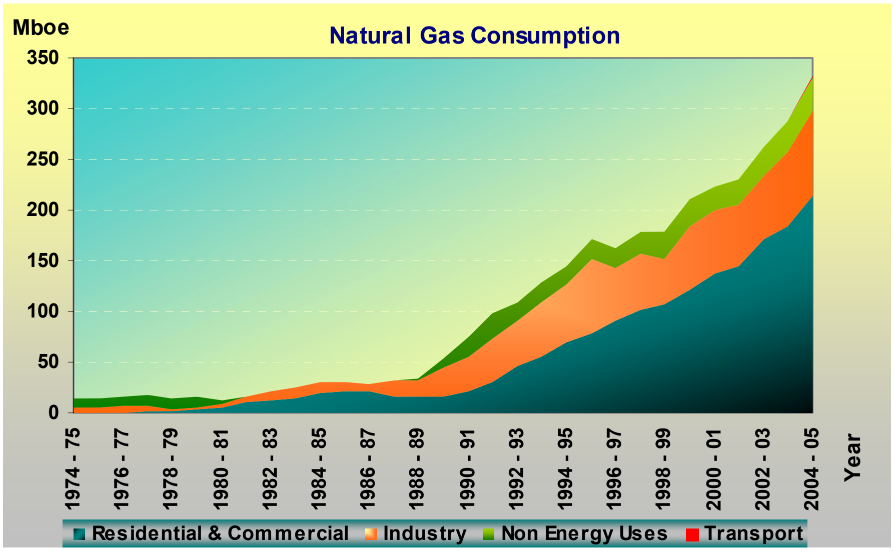
Natural Gas

Shown below is Iran's natural gas production and consumption. It shows that the country consumes more gas than it produces. Iran has still, however, increased its natural gas production for future export.



Source: Iran Ministry of Energy 2006b

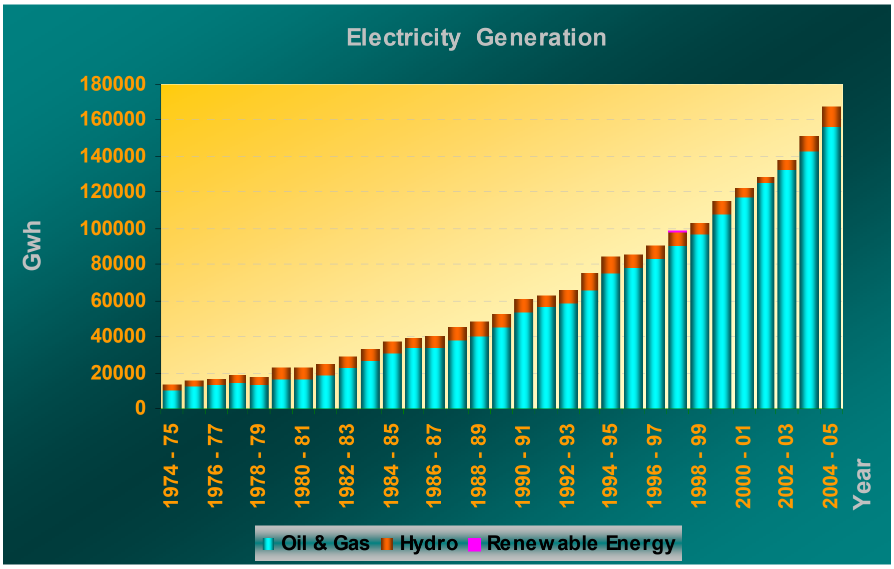
Based on the following graph the ratio of natural gas consumption in buildings compared to other sectors increases annually. Today most natural gas is consumed in buildings.



Source: Iran Ministry of Energy 2006b

Electricity

More than 93% of Iran's electricity is generated from oil and natural gas (primary energy), 6.6% from hydro, and less than 0.03% through renewable energies. The generation of electricity from oil and natural gas is very inefficient in Iran. Therefore the use of electricity is not recommended as a pure energy.



Source: Iran Ministry of Energy 2006b

Renewable Energy

Iran's renewable energy accounts for only about 0.0038% of its total energy supply (Iran's Ministry of Energy, Energy Planning Department, 2006).

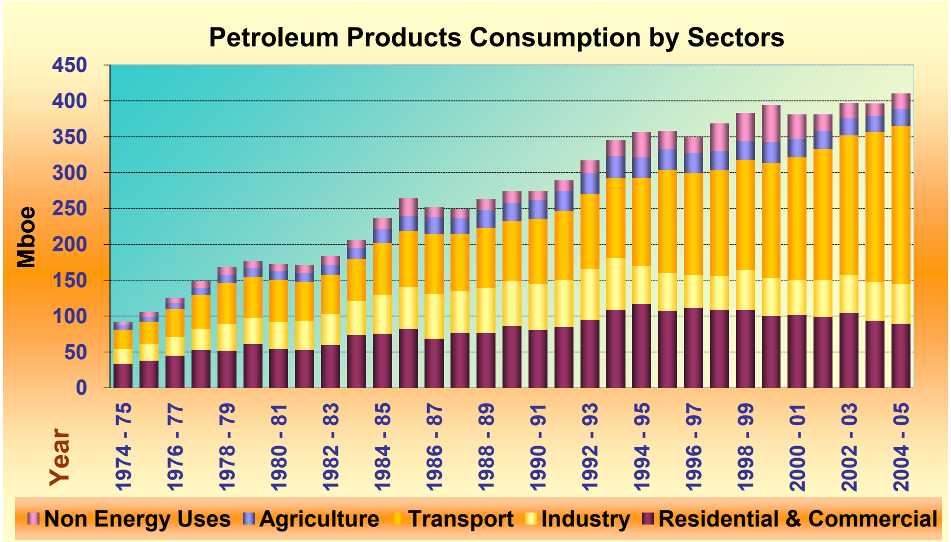
Energy Consumption by Sectors

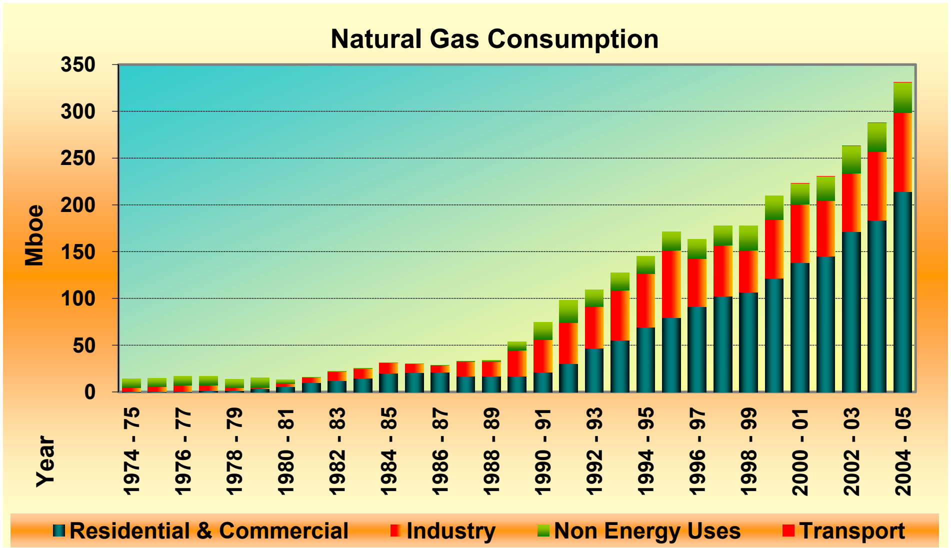
The following table presents the percentages of energy consumption for various sectors including residential and commercial, industrial, transport, and agricultural sectors. In 2004-05, 40.58% of Iran's energy was consumed by the residential and commercial sector. Thus, in comparison with the other sectors, this sector is the biggest consumer.

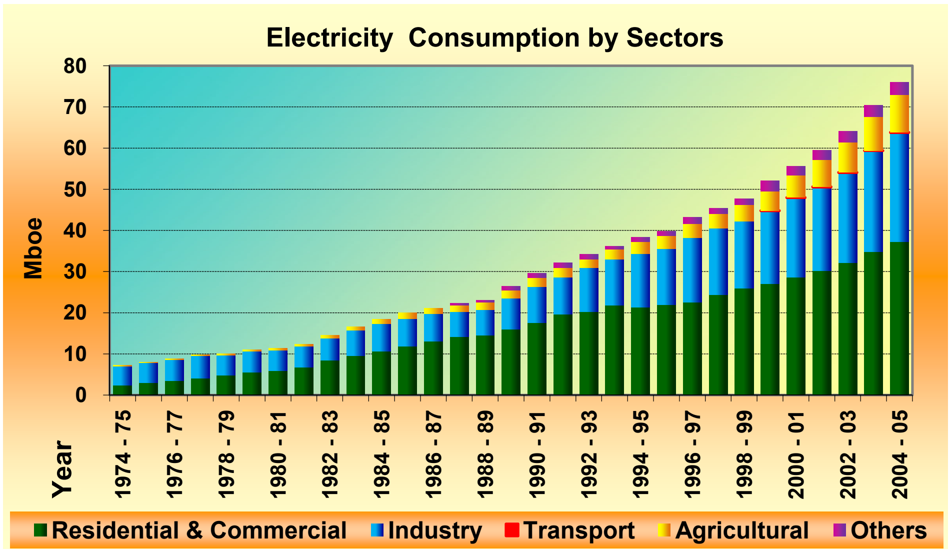
Table 10: Percentage of energy consumption by sectors, Source: Iran Ministry of Energy 2006b

Year	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05
Residential & Commercial	30.69	31.07	34.32	36.37	37.68	37.65	39.00	38.83	38.23	38.51	40.20	39.97	41.57	40.14	40.58
Industrial	29.22	29.14	27.65	24.03	23.12	24.39	20.55	21.83	19.20	21.25	21.02	20.46	19.90	20.66	20.36
Transport	24.10	23.21	22.78	23.23	25.69	25.01	25.11	24.75	25.18	26.06	27.23	28.00	28.07	28.20	27.73
Agricultural	7.44	7.12	6.81	5.88	5.66	5.44	5.22	4.79	5.17	4.63	4.57	4.38	3.94	4.03	3.81
Non - energy uses	8.24	9.19	8.21	10.34	7.68	7.32	9.83	9.60	12.00	9.18	6.63	6.84	6.14	6.60	7.14
Other Uses	0.28	0.27	0.25	0.16	0.18	0.19	0.28	0.22	0.23	0.38	0.33	0.35	0.37	0.35	0.36

The following series of graphs compare the energy consumption per sector of several fuel types from 1974 to 2005. It can be seen that residential and commercial energy consumption has decreased for petroleum products and increased for natural gas and electricity in recent years.







Source: Iran Ministry of Energy 2006b

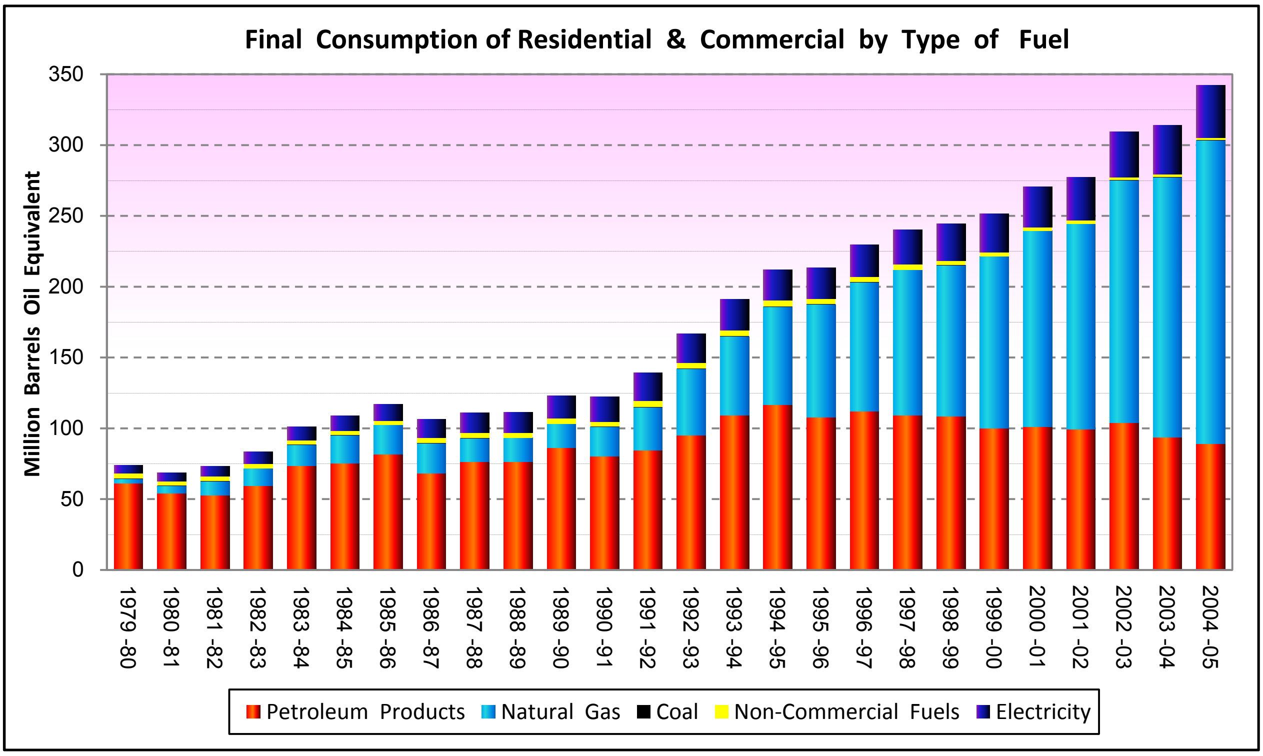
Energy Consumption by Buildings

Despite recent fluctuations, the percentage of energy consumption of residential and commercial buildings has increased from 30.69% in 1990-91 to 40.58% in year 2004-05. For this reason, a reduction in building energy consumption is very important.

Building energy consumption in Iran is very high at 582kWh/m²a for cold regions and an average of 310kWh/m²a. Iran plans to reduce this average to 160kWh/m²a by 2010 (Iranian fuel conservation organization 2005a, p.1).

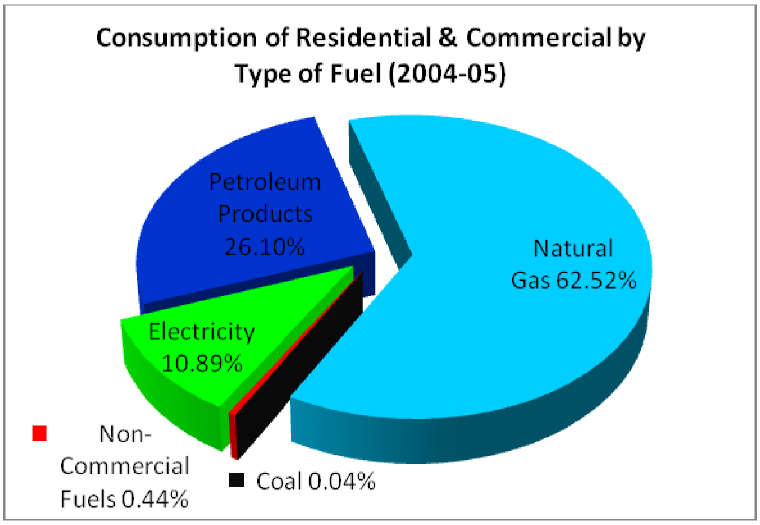
Residential and Commercial Energy Consumption by Fuel Type

The following graph shows the final residential and commercial energy consumption by fuel type. It shows a yearly increase in the total energy consumption for residential and commercial buildings as well as a significant increase in natural gas consumption (which coincides with a recent reduction in the consumption of petroleum products). The ratio of electricity consumption has also increased slightly and the ratio of non-commercial fuels has steadily decreased in recent years.



Source: Based on data from Iran Ministry of Energy 2006b

This graph shows the percentage of energy consumption for the various fuel types in the residential and commercial sector for 2004-05. The majority of residential and commercial energy consumption (62.52%) was supplied by natural gas. Although petroleum products were the most commonly used fuel type before 1980, they only accounted for approximately 26.10% of energy consumption in 2004-05.

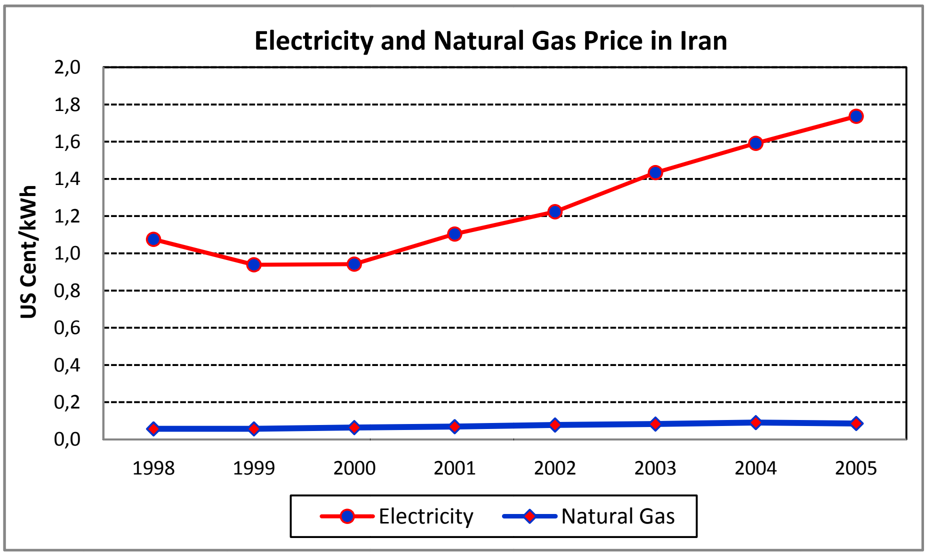


Source: Based on data from Iran Ministry of Energy 2006b

Energy Price

Iran provides extensive subsidies on items such as energy, food, and bank credit. Implicit and explicit energy subsidies reached 17.5% of Iran's GDP in 2005-06, while total subsidies were estimated at over 25% (Tata et al. 2007, p.14). According to Sarbib et al. (2001a, p.vii) and Tarr and Jensen (2002, p.3), subsidies for petroleum products cost the government an estimated 18 percent of Iran's GDP.

Because of energy subsidies, Iran's fuel product prices are among the lowest in the world, with gasoline priced at about 9 U.S. cents per litre. The low prices have led to a rapid growth in domestic consumption with adverse environmental implications (Tata et al. 2007, p.14). Petroleum prices in Iran are only about 10 percent of world prices (Sarbib et al. 2001a, p.vii, Tarr and Jensen 2002, p.3). The following graph represents the electricity and natural gas price in Iran from 1998 to 2005, both of which are very low.



Source: Based on data from Iran Ministry of Energy 2006a, p.11, Table 1-1 and Energy Information Administration 07.06.2007

Not only is the energy price low in Iran, but the inflation rate is as well. The average inflation rate of energy carriers from 1997 to 2005 was 17.37 % and that of natural gas and electricity, used for heating and cooling, was 12.1% (Iran Ministry of Energy 2006a, p.10).

The following table shows the nominal and actual inflation rates of energy carriers from 1987 to 2005. It shows that the actual inflation rate of some energy carriers such as natural gas and elecrticity is negative, and that the average actual inflation rate of all energy carriers is 1.97%.

Table 11: Nominal and actual inflation rate of energy carriers in Iran (1997-2005), Source: Based on data from Iran Ministry of Energy 2006, p.10

1997-08-2005-06	Par/Nominal Inflation Rate (%)	Actual Inflation Rate (%)
Fuel Oil	21.4	5.5
Gas Oil	19.4	3.7
kerosene	19.4	3.7
Gasoline	22.3	6.3
Liquid Gas	14.9	-0.2
Natural gas	10.9	-3.6
Electricity	13.3	-1.6

Building

Introduction

Uncomfortable climatic conditions in the climatic regions of Iran have forced Iranians to develop suitable climate responsive methods and apply them to traditional architecture in all climates. Therefore most of Iran's traditional houses (especially those in warm climates) are climate responsive and have comfortable conditions with minimal use of heating and cooling devices. Village architecture was free from the urban and architectural rules of the city, and the use of mechanical heating and cooling features was limited, so the traditional houses of villages were more climate responsive.

About 100 years ago, with the change of living characteristics and facilities and the increased usability of mechanical heating and cooling features, the architecture of Iranian houses completely changed. The Iranian started to apply the western architectural features, but I think for more successful application in Iran, the western architecture needed more adaptations to certain climates.

These days almost none of the traditional climatic rules and architectural heating and cooling techniques are used in new buildings. Not only are the buildings designed with no concern for climatic conditions, but the urban characteristics, and orientation, width, and height of streets are not designed according to climatic conditions.

There are some official rules demanding the use of building components (such as walls, roof, floor, windows, and doors) with specified thermal resistance. However, they are not effectively used in individual houses. One of the main reasons for this is the low price of oil. Today, although some architectural rules vary between the climates of Iran, the main rules apply throughout the entire country. Therefore the buildings of different climates are almost the same with no attention to climatic conditions. The city of Tabriz is located in the province of East Azarbaijan. General characteristics of the houses in East Azarbaijan are stated below:

Table 12: General characteristics of East Azarbaijan houses in 1996, Source: Iranian fuel conservation organization 10.09.2005

Total site area of residential buildings ~(m^2)	No. of houses	No. of families	Average site area (m^2)	Average built area (m^2)	No. of occupants	No. of family members
95000 000	378104	446159	251	164	6.08	4.78

Traditional Housing in Tabriz

The principle of thermal control through [proper architectural design and] proper use of materials is well illustrated in traditional buildings which meet the demands of the climate. Therefore a good method of approaching a design concept is to analyse traditional settlement patterns and building types, especially for solutions aiming at natural climate control (Gut and Ackerknecht 1993, p.65).

Some traditional housing in Tabriz will be studied to discover how some of their architectural factors are adapted to cold climates, especially that of Tabriz. This will also highlight the most important architectural factors in adapting housing to the climate. The main purpose of this research, however, is not to learn from traditional buildings.

The houses in the traditional Tabriz are mainly inwardly oriented, and the buildings in the whole city make an inter-connected structure. They make a maze that is only organic but not geometric at all. In this traditional part of the city most of the buildings are connected to each other on three sides, with the remaining side facing the street, lane, or alley (Kasmaei 2005, pp.76-78).

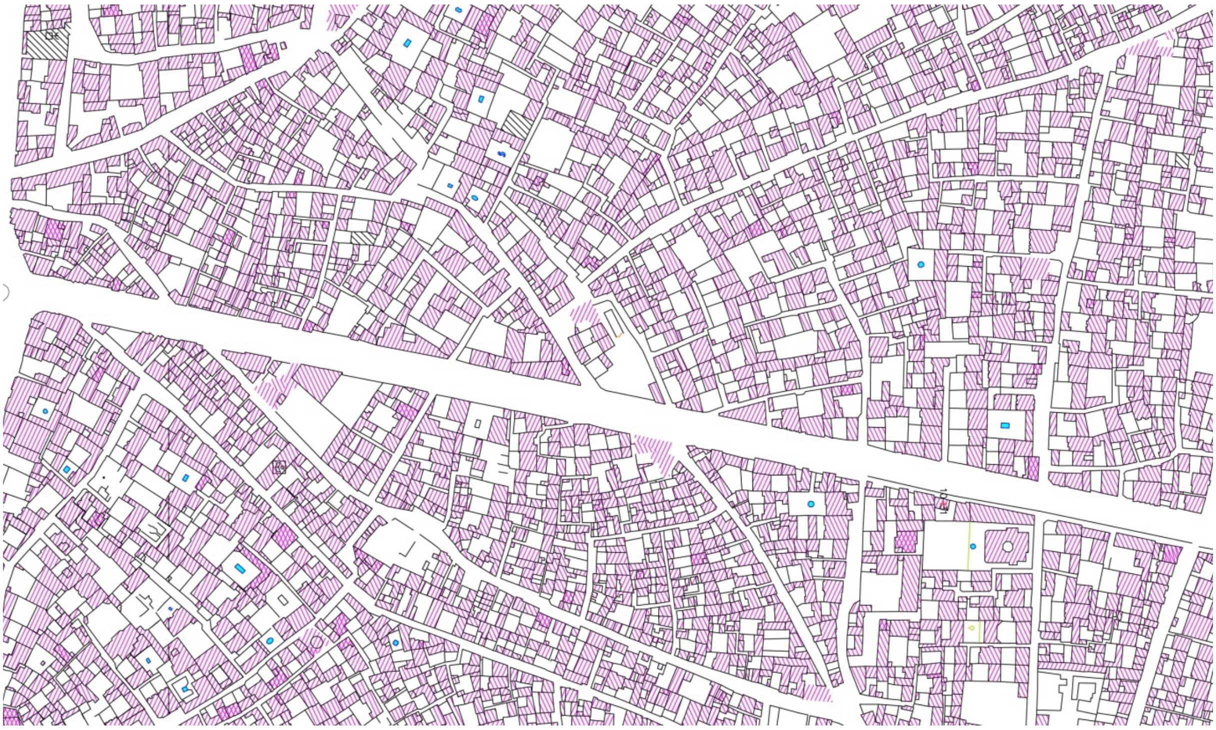


Figure 48: A traditional part of the city of Tabriz, Source: Municipality of Tabriz 2006 (my adaptations)

Traditional houses of Tabriz are inward-oriented with most of their spaces opening to a courtyard. The orientation of these buildings varies from southwest facing to southeast facing. The most important parts of the buildings are located to the north of the site (ranging from northwest to northeast), facing south.

Most of the houses also have a cellar extending to approximately 1m above ground level. The important spaces of the house are located in front of the courtyard and oriented to the south. The auxiliary spaces are located behind the main spaces or at the corners of the courtyard. This allows the important spaces to receive solar radiation and daylight during the day and prevents them from losing heat energy through the north walls. In most Iranian houses, the spaces do not directly open to the courtyard. They are instead connected to the courtyard through a doorway or terrace (Kasmaei 2005, p.87).

Most of houses have also a columnar terrace in front of the important spaces. These are timber columns, sometimes covered with gypsum. The walls are thick (between 60 and 120cm) and are constructed from brick and adobe. The roofs are flat and built from timber beams, straw (bamboo, etc.), clay, and straw-clay[1] plaster. Most of these buildings also include central pools, gardens, and vegetation in large courtyards.

Some traditional houses have two windows close together[2] to reduce heat loss. Some walls have a chamfer into the indoor spaces to allow more solar radiation through (Kasmaei 2005, p.87).

Traditional Housing Examples for Tabriz

House 1

This is a two-story building oriented 15° east of south with a large courtyard. The building's main spaces, such as main living spaces, are located on the second story. The main spaces of this house are located to the south with other less important spaces located to the north (behind these spaces). The indoor spaces open to the courtyard through a columnar terrace. The walls are built of brick and adobe and are very thick. North and south facing walls are up to 1.6 and 1.8m, respectively, and east and west facing walls are up to 1.2m. All spaces have large timber windows which receive solar radiation during the winter and are protected from summer sun by the overhang of the terrace roof (Kasmaei 2005, p.80).

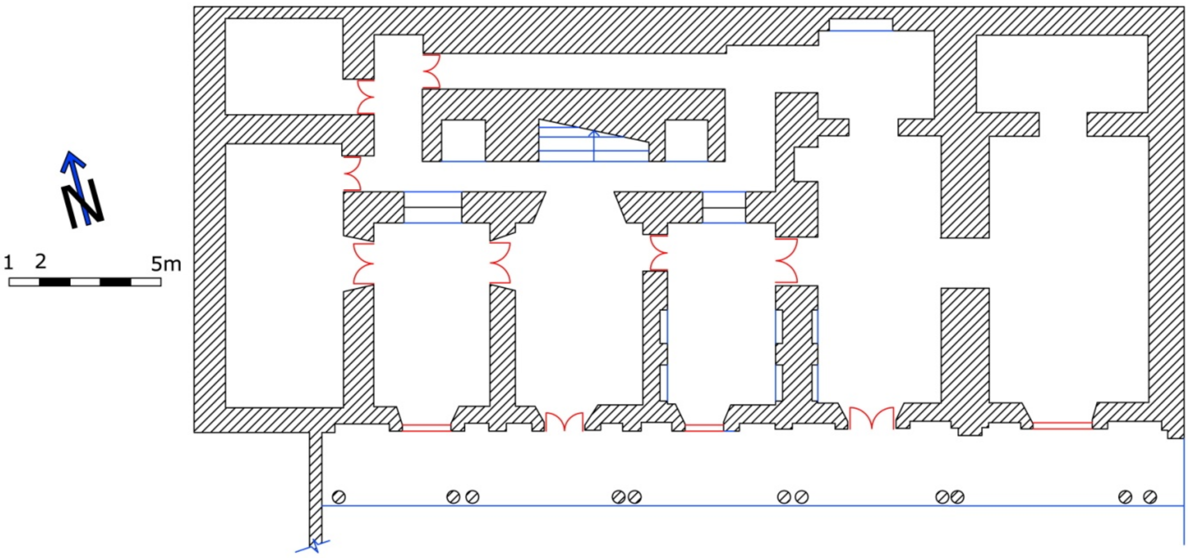


Figure 49: Ground floor plan, Source: Kasmaei 2005, p.81 (my drawings)

[1] - Plaster made of clay and straw.
[2] - Double window.

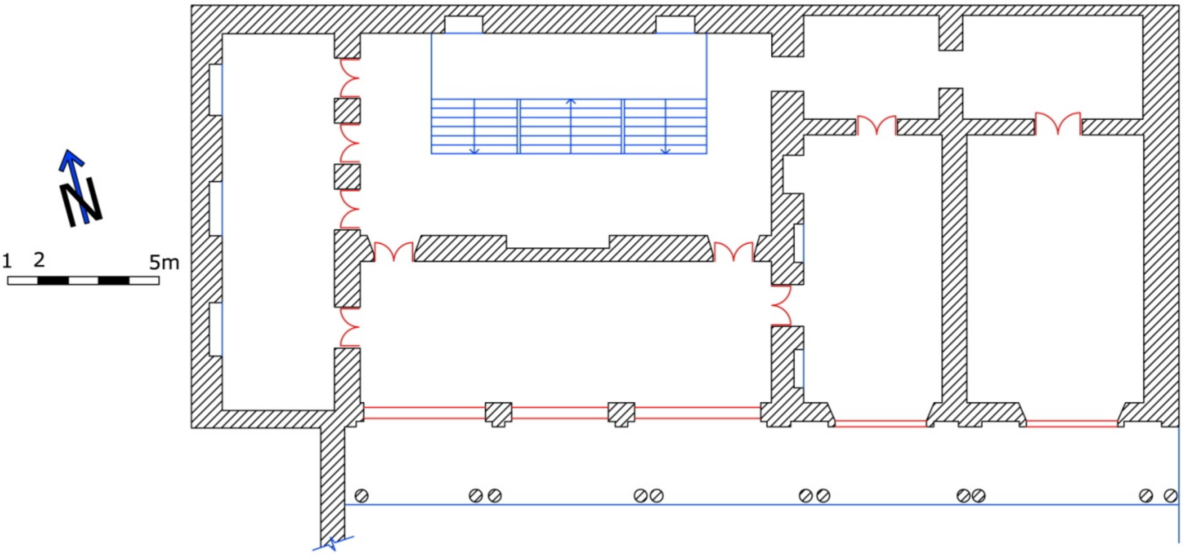


Figure 50: First floor plan, Source: Kasmaei 2005, p.81 (my drawings)

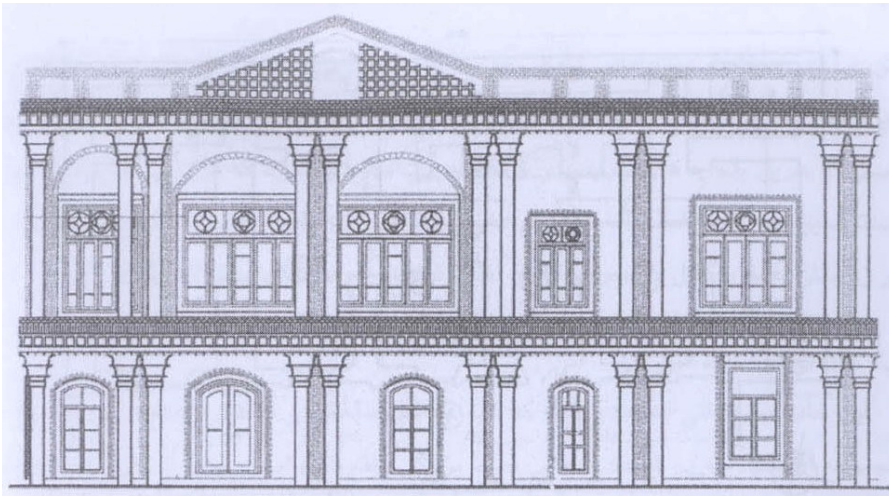


Figure 51: South-facing elevation, Source: Kasmaei 2005, p.82

House 2

This is a two-story building oriented to the southwest, also with a large courtyard. The main spaces are located to the southwest to receive solar radiation. The indoor spaces are connected to the courtyard by a doorway. The windows are large and are located on the external surface of the walls to allow more solar radiation through to the internal spaces. The walls of this house are approximately 1.1m thick (Kasmaei 2005, p.84).

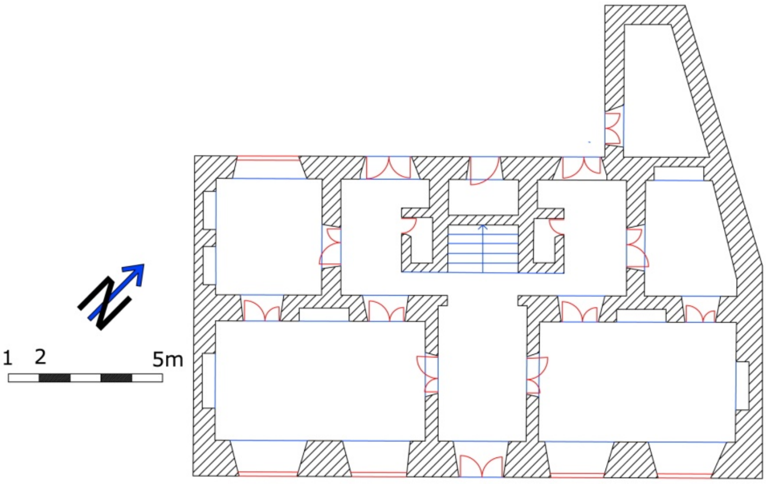


Figure 52: Ground floor plan, Source: Kasmaei 2005, p.82 (my drawings)

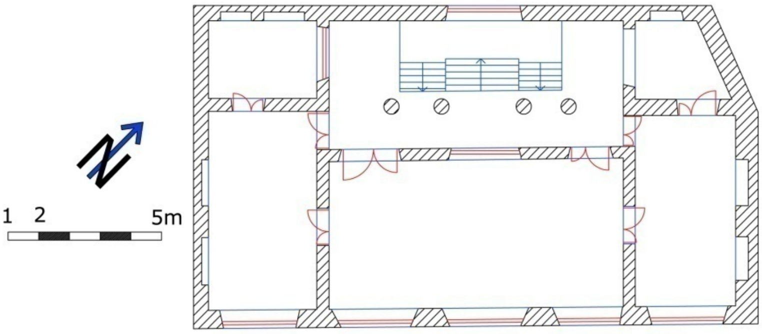


Figure 53: First floor plan, Source: Kasmaei 2005, p.83 (my drawings)

House 3

This is a two-story building oriented to the southwest and located to the north of a large courtyard. A doorway connects the indoor spaces to the courtyard. The walls are made of stone to a height of 1m above ground with brick and adobe above that. The important and living spaces of this house are located to the southwest with the unimportant spaces behind them (Kasmaei 2005, p.84).

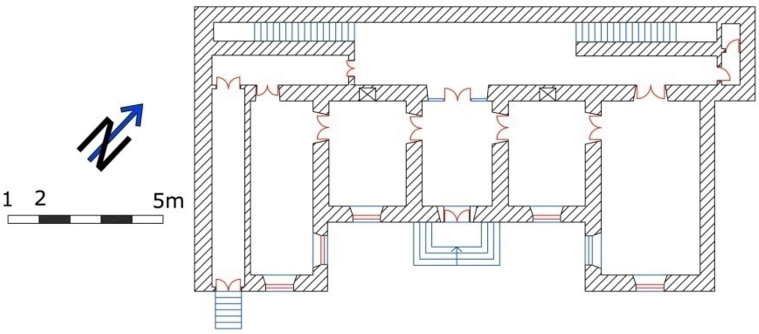


Figure 54: Ground floor plan, Source: Kasmaei 2005, p.85 (my drawings)

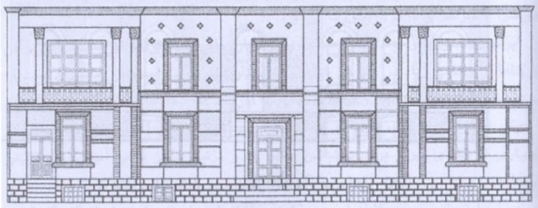


Figure 55: Southwest-facing elevation, Source: Kasmaei 2005, p.85

House 4

This is a single-story building facing south with a basement story. All of its indoor spaces are oriented to the south and connected indirectly to the outside through a closed doorway. The wall thickness of this house is 80cm (Kasmaei 2005, p.84).

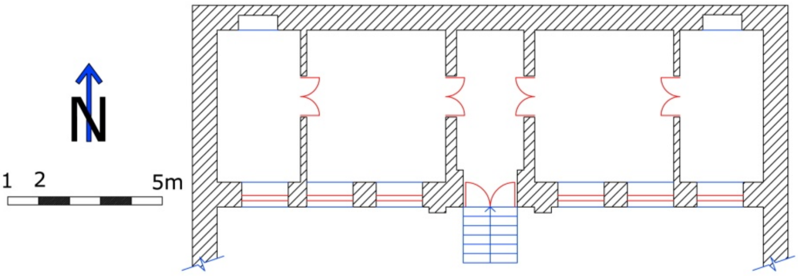


Figure 56: Ground floor plan, Source: Kasmaei 2005, p.86 (my drawings)

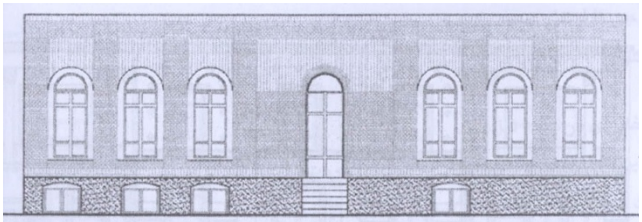


Figure 57: South-facing elevation, Source: Kasmaei 2005, p.86

Results

In almost all traditional houses of Tabriz, the following design strategies are used to reduce their energy consumption:

- Orientation to the south (ranging from southwest to southeast).
- Building elongation along the east-west axis.
- Opening of the indoor spaces indirectly into the courtyard, through a closed doorway acting as a thermal buffer.
- Use of thick walls.
- Lack of windows and other openings in the north, west, and east-facing walls, and large windows in south-facing walls.
- Southern location of all important spaces and northern location of unimportant spaces (as a thermal buffer zone between important spaces and the north wall).
- Location of windows at the external surface of walls.
- Glass windows in external doors, to receive solar heat.

New Individual Low-Rise Houses of Tabriz

In both Tabriz and Iran in general, most houses sit on a rectangular site, often with two or three neighbouring buildings adjacent. Most of these sites lie on a north-south or east-west axis.

Figure 58: Site plan of a neighbourhood unit in a new part of Tabriz, Source: Municipality of Tabriz 2006 (my adaptations)

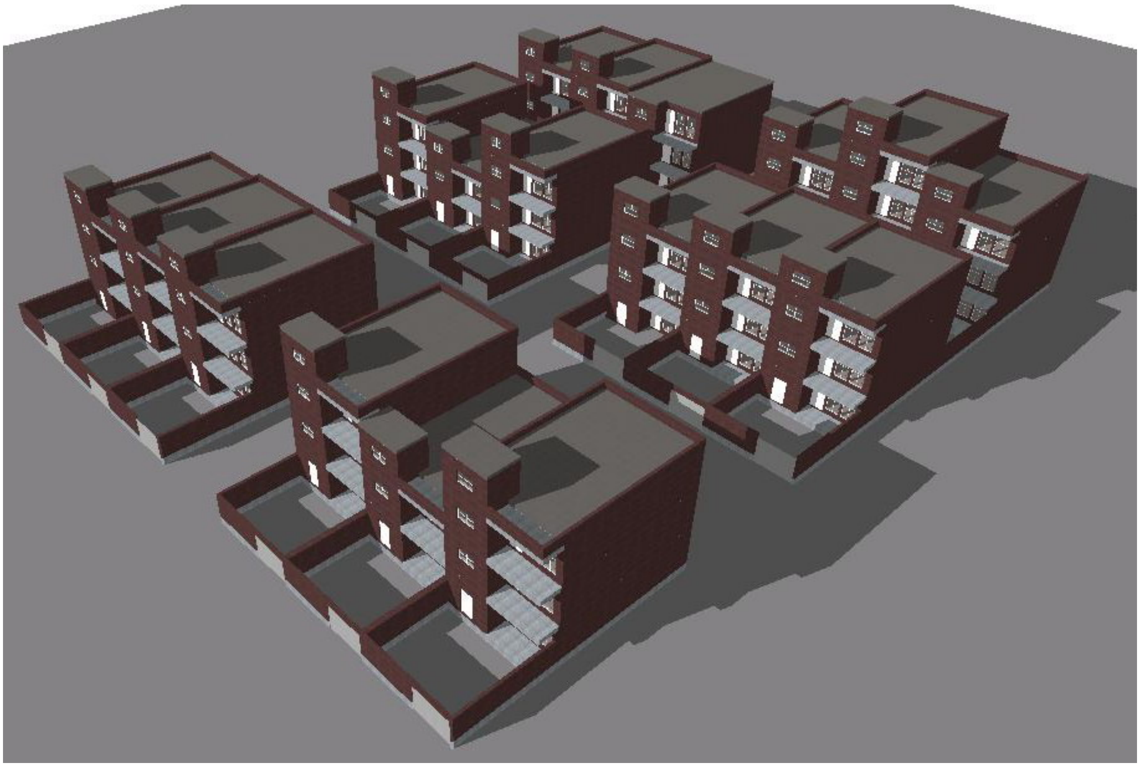


Figure 59: Aerial view of a typical neighbourhood unit

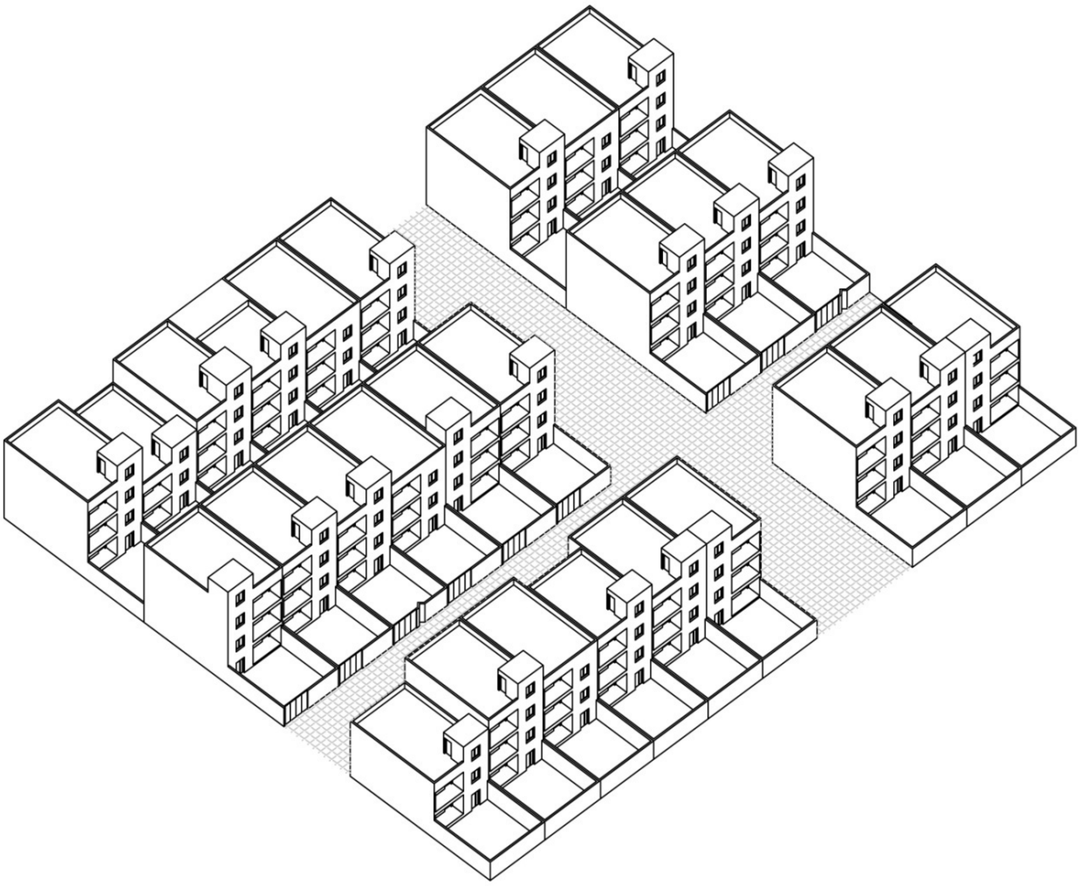


Figure 60: Aerial view of a typical neighbourhood unit

The average site area of houses in the province of East Azarbaijan is approximately 250m² with a built area of about 164m² (it therefore should be a little less in Tabriz). The built area of most of the houses is often adjacent to the other houses in the left and right. These adjacent build areas are either controlled or uncontrolled.

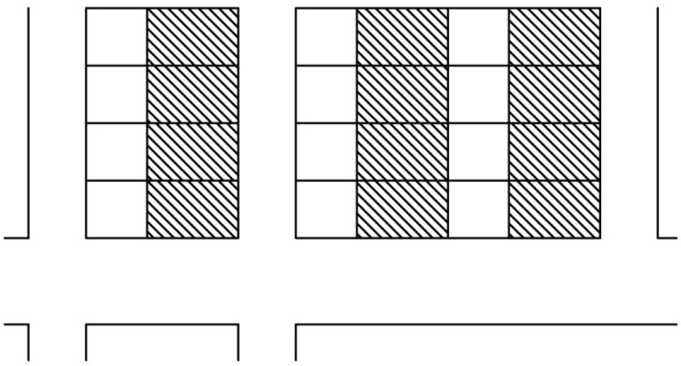


Figure 61: Site plan of a general neighbourhood unit in Tabriz

Building regulations in Iran state that only 60% of the site can be built on and the remaining area (40%) must be used as courtyard. Courtyards must be located on the southern side of south-north orientated sites and on the eastern side of sites orientated east-west. These rules intend to maximize the solar energy through the wide windows that are open to the courtyard. Therefore, some houses are east-facing but the majority face south.

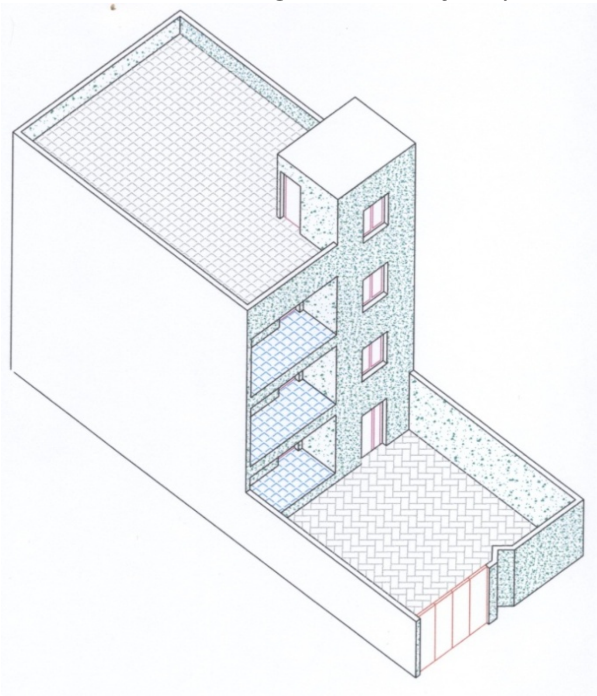


Figure 62-63: Aerial view of a typical new 3-story house in Tabriz

Houses and Neighbourhood Typology

Typology

Due to the previously mentioned rule, new, individual, low-rise houses have only one typology.

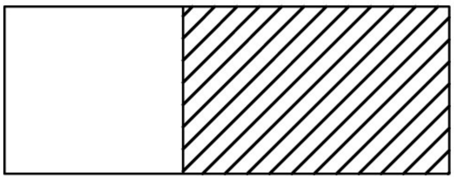


Figure 64: The main type of houses

This typology has some sub-typology, which are very similar.

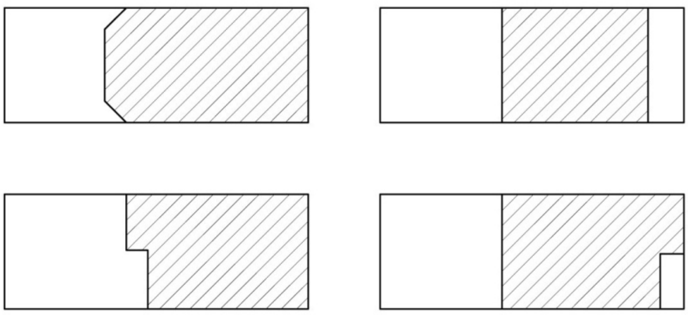


Figure 65: Different subtypes of houses

These buildings usually have two or three levels and, although these are individual houses, every level is a separate residential unit with a common staircase and sometimes a common courtyard. It is common for the owner of the building to live in one story and rent the two additional levels to other families.

Privacy

For cultural and religious reasons, household privacy is very important for Iranians. Both women and men desire privacy in their homes as well as visual segregation from the street and other buildings. Therefore, individual low-rise houses have private courtyards, separated from the street and neighbouring buildings with walls of 2.5m. Windows to the street are located at a height of more than 2m. This is an example of an individual house in Tabriz:

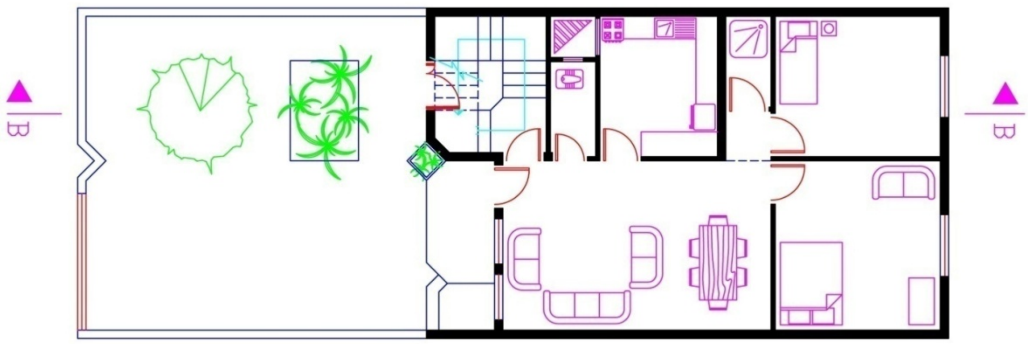


Figure 66: General housing plan, Scale: 1/200

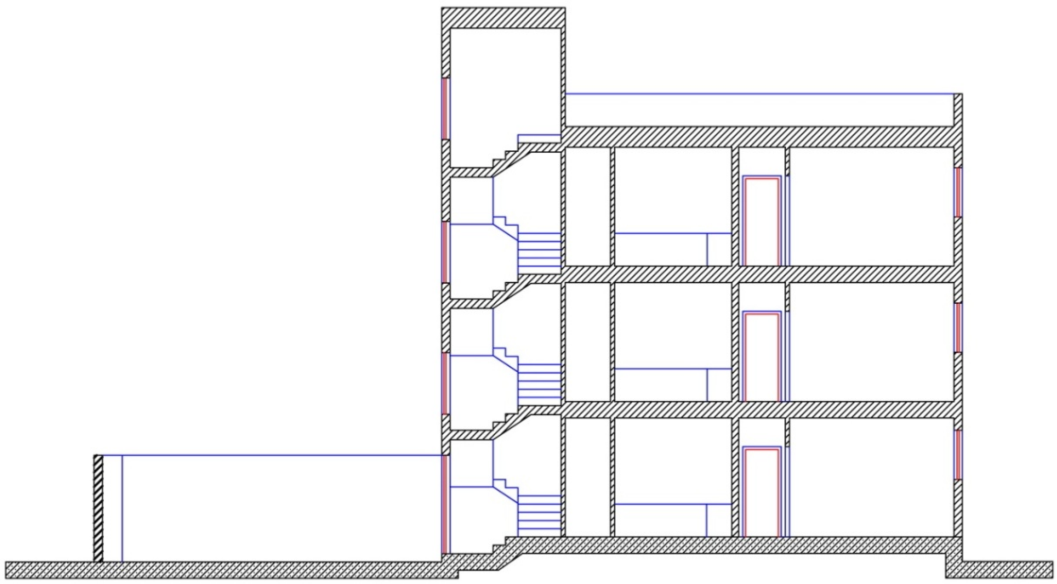


Figure 67: B-B Section, Scale: 1/200

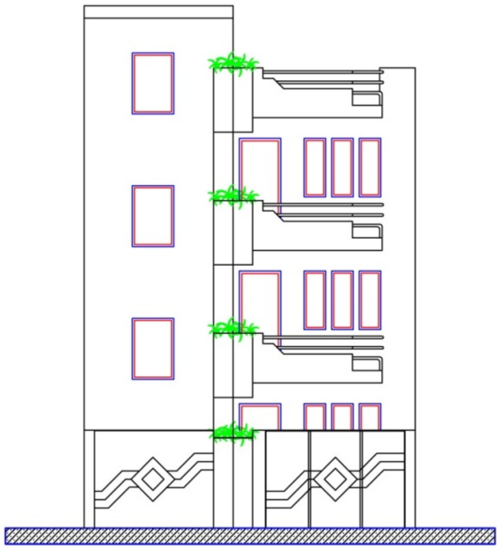


Figure 68: South elevation, Scale: 1/200

Construction Materials

Throughout all climatic regions of Iran most new buildings, especially individual houses, are built with masonry materials. Due to building regulations, one and two story houses can be constructed using masonry (often bricks) and a concrete structural framework. However, buildings over two stories must use a concrete or steel skeleton and the external and internal walls must be constructed with bricks. In addition, the roofs are concrete or occasionally brick with steel beams. Very few low-rise individual houses are built with prefabricated materials or light-weight materials. In 1987, approximately 80% of new houses were built with brick and steel in the cities of East Azarbaijan.

Energy Saving Regulation in Buildings

There are no rules or standards for the amount of energy consumption (per m^2) of a building in Iran and there is only chapter 19 of "Iranian National Building Code" that prescribes the amount of thermal resistance and thermal transmittance of components comprising the thermal envelope.

Based on "Code 19", the amount of thermal resistance (and thermal transmittance) of different components of the external envelope for different buildings depend on: building usage, climate of the region, amount of heating and cooling degree days, and population of the city in which the building is situated. The amounts of thermal resistance for residential buildings in the city of Tabriz in prescriptive approach[1] are shown in the following table.

[1] - For the building envelope, a prescriptive approach would list the minimum R-value or maximum U-factor requirements for each building component, such as windows, walls, and roofs (U.S. Department of Energy 09.07.2008a).

Table 13: Minimum thermal resistance of opaque thermal envelope components (Prescriptive Approach), Source: Ministry of Housing & Urban Development 2001, p.28

Building component	Building component type	Thermal resistance (m²K/W)
Wall	Light[1]	2.8
	Heavy[2]	1.9
	Adjacent to uncontrolled space	1.5
Roof	Light	5
	Heavy	4
	Adjacent to uncontrolled space	3.1
Floor	Light	3
	Heavy	2.4
	Adjacent to uncontrolled space	1.8
Floor at earth	Ground circumstantial insulation	3.7
	Floor insulation	1.7

The amounts of thermal transmittance of Tabriz in performance approach[3] are shown in following table.

Table 14: Thermal transmittance of thermal envelope components (Performance Approach), Source: Ministry of Housing & Urban Development 2001, p.26

Energy type (carrier)	Non-Electricity	Electricity
Building component	Thermal transmittance (U-Factor) (W/m²K)	
Wall	0.8	0.67
(Flat or tilted) Roof	0.5	0.42
Floor above open space	0.5	0.42
Floor at earth	1.45	1.21
Transparent envelope	2.7	2.25
Door	3.5	2.92
Uncontrolled Space	0.55	0.46

Heating and Cooling

In residential buildings situated in the cities of Iran with low air humidity, evaporative coolers (also called swamp, desert, or air coolers) are used as cooling equipment, because the installation and operating cost of this cooling equipment is much lower than refrigerative air conditioning. Evaporative cooling is especially well suited to climates where the air temperature is high and humidity is low. This cooling equipment requires electricity.

In residential buildings in warm and humid climates, different refrigeration systems are used for cooling. In small residential buildings and personal houses

[1] - Light building component is a component, that its effective surface mass of partition is less than 150 Kg/m² (Ministry of Housing & Urban Development 2001, p.28).

[2] - Heavy building component is a component, that its effective surface mass of partition is more than 150 Kg/m² (Ministry of Housing & Urban Development 2001, p.28).

[3] - Performance approach allows comparing proposed design with a baseline or reference design and demonstrates that the proposed design is at least as energy efficient as the baseline in terms of annual energy use. This approach requires an annual energy analysis for the proposed and the reference buildings (U.S. Department of Energy 09.07.2008a).

various (non-central) cooling equipments are used that are different types of heat pumps. Single and non-central coolers, including evaporative and refrigerative coolers are widely used, by 66.6% (Central Bank of Iran 2007b, p.14) of Iranian families. In some of the new high-rise residential buildings and apartments, and most administrative/official buildings, central cooling systems which include a chiller with air handling unit or fan-coil, is used for cooling purposes.

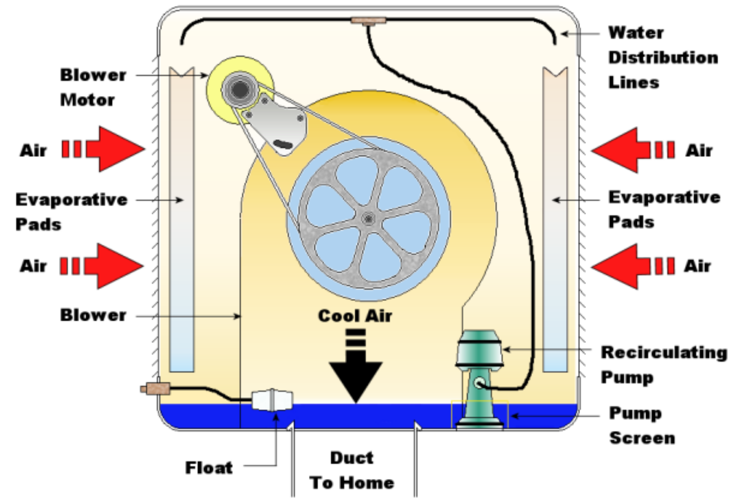


Figure 69: Evaporative cooler, Source: Wikipedia 10.08.2008

In the past, small and individual houses of cold climatic region of Iran used no cooling equipment and the buildings were cooled via natural ventilation or ceiling fans[1]. These days mechanical fans are also used for cooling such that 59.2% (Central Bank of Iran 2007b, p.15) of Iranian families use them. However, recently most new houses of this climate use evaporative coolers, because the cold climatic region of Iran has a dry summer. Most cooling systems of Iran consume electricity and some refrigeration cooling systems consume natural gas.

In most of the general individual houses of Iran, heating stoves are used as heating equipment. These heating stoves often consume natural gas and in some cases kerosene. In some new buildings and especially in apartments, a central heating system with air handling units, radiator or fan-coil is used for heating purposes. The central heating systems of buildings in Iran consume gas oil and natural gas. Central heating with a radiator is used by 10.3% (Central Bank of Iran 2007b, p.14) of Iranian families.

Recently, heating packages are used for heating purposes and split units are used both for heating and cooling purposes in some buildings. But only 1% (Central Bank of Iran 2007b, p.14) of Iranian families use heating packages as heating equipment.

[1] - An electrically powered mechanical fan suspended from the ceiling of a room used to produce airflow for cooling purposes.

Chapter Three: Germany

State of Knowledge

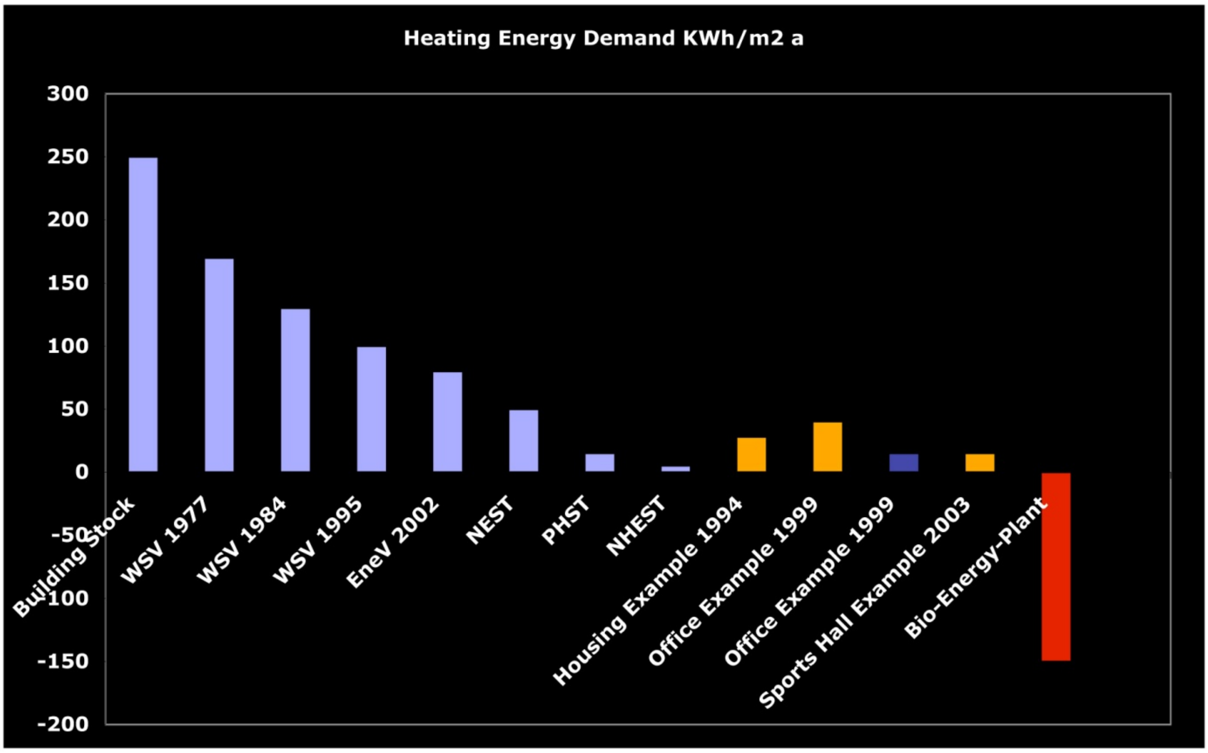
After the "Oil Crisis" of 1973, the German government tried to reduce the energy consumption through research, the use of renewable energies and also with energy saving in buildings. Energy saving in buildings started with the introduction of new regulations about energy demands of buildings.

The building energy regulations were called "thermal insulation regulation (WSchV)" until 2001 and were only focused on housing and the winter heating period. In 2002, it was changed into "Energy saving regulation (EnEV)" and includes the influence of building technology supply. It is measured in primary energy and EnEV 2006 also includes the energy demand of ventilation, cooling, electricity and lighting. From 1977 to 2002 the admitted maximum heating energy demand of new buildings was reduced from 170kWh/m²a to an average of 80kWh/m²a (Steffan 2006). Some of the main regulations are Thermal Insulation Ordinance of 1977, 1984 and 1995 and also Energy Saving Ordinance of 2002, 2004 and 2007.

Due to the importance of energy saving and reduction of CO_2 production in Germany, it has also focused on energy saving in buildings by doing research, writing theses and books, and making practical rules and standards. There are different governmental and nongovernmental organisations and firms, which work or research energy saving in buildings and most architecture faculties have at least one institute working on energy saving in buildings and energy-efficient architecture. Energy saving in buildings is a rapidly growing topic in Germany and a lot of detailed research and innovation has already been produced.

There have also been a lot of passive, zero energy and autonomous houses built as well as sustainable buildings in Germany. In the last few years development in this area has increased and there has been a lot of energy efficient and sustainable non residential buildings built, such as, energy efficient office buildings, schools and kindergartens, passive and sustainable housing settlements and plus energy buildings.

The following graph shows the different building standards and different energy efficient buildings existing in Germany, as well as their energy consumptions. It compares the amount of heating energy consumption for each type. The four buildings on the right of the diagram show the energy-efficient example buildings, which were built in Germany. Not only are there passive and zero energy buildings in Germany but there are also plus-energy buildings, in which energy supply is more than energy consumption. Bio-Energy-Plant is a plus energy building, which supplies its energy with photovoltaic solar cells.



Heating energy demand of different building standards and available buildings[1] Source: Claus Steffan, 2006

Comparison of Iran and Germany

There have been a lot of researches done about energy saving in buildings in Germany, a lot of books are written about it and there are many existing energy efficient examples and model buildings. Germany has a lot of theoretical and practical experience in this field and is also one of the most successful countries in reducing the energy consumption of buildings. Therefore, Germany and its building standards will be studied and compared with Iran. By comparing Iran and Germany an analysis of the available science and new standards of energy efficient buildings in Germany will show how much and how the theoretical and practical experiences of Germany can be applied to Iran. German passive houses are suitable for cold climates. The cold climatic region of Iran has a very cold winter climate and warm summer climate.

Simulation of passive houses in cold climatic region of Iran shows that not only are passive houses suitable for winter conditions of this region, but they are also more easily achievable, and that they need less insulation. However, in the Iranian summer, this kind of houses will become too warm, and if they should be used, they must be given some modifications for appropriate use in the cold climatic region.

[1] - WSV: Wärmeschutzverordnung (Thermal Insulation Ordinance)
EnEV: Energieeinsparverordnung (Energy Saving Ordinance)
NEST: Niedrigenergiestandard (Low-energy standard)
PHST: Passivhausstandard (Passive house standard)
NHEST: Null-Heiz-Energie Standard (Zero heating energy standard)

Climate

Climatic Zones

Based on Köppen's climate classification, almost all of Germany is situated in one climatic zone, namely "cfb" (Kottek et al. 2006, p.1). Therefore, for more details about the climatic zones of Germany another climate classification is utilised. USDA zone map is usually used for the minimum temperature in winter and is based on the average minimum temperature (Tropen Garten 25.12.2007). It is a climatic division from U.S. Department of Agriculture, in which North America is divided into 10 zones. In this division, with the exception of zone 1 and zone 10, all zones are divided to semi-zones "a" and "b". A zone comprises 10 degrees Fahrenheit or 5.5 degrees Celsius. Europe is also divided based on USDA-Map by Heinze and Schreiber by converting it into degrees Celsius and by adding zone 11 (Janda 12.8.2004). This plan shows the climatic regions of Europe based on USDA-Map. It consists of zones numbers 5 to 10.

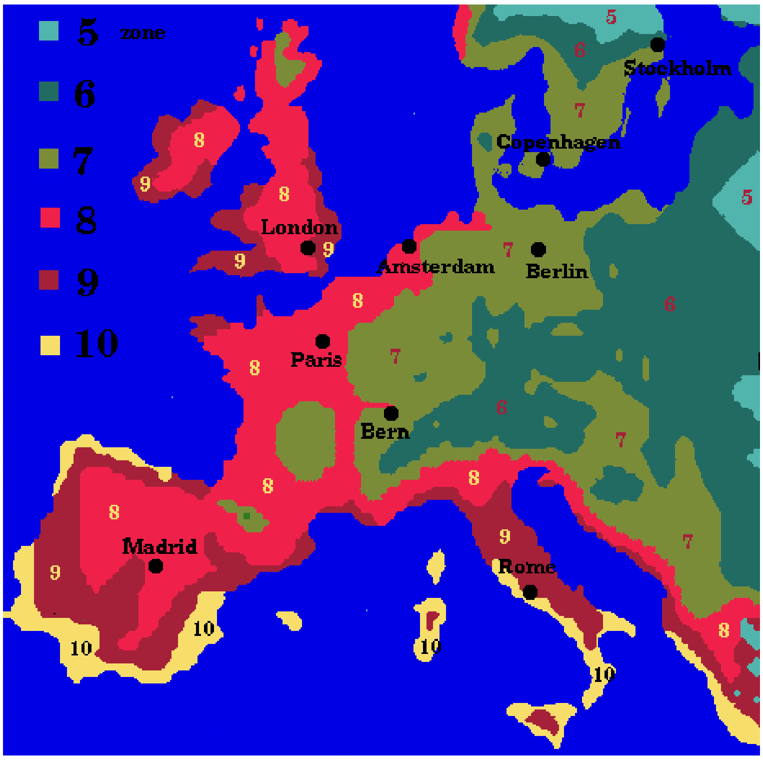


Figure 70: USDA-zones in Europe, Source: Veen 25.12.2007

USDA climate zones follow the temperature differences specified in the following table.

Table 15: Temperature differences of USDA climate zones, Source: Tropen Garten 25.12.2007

Climate Zone	5		6		7		8		9		10	
Semi-zone	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	10a	10b
Minimum Temperature	- 28.8 to - 26.2	- 26.1 to - 23.4	- 23.3 to - 20.6	- 20.5 to - 17.8	- 17.7 to - 15.0	- 15.0 to - 12.3	- 12.2 to - 9.5	- 9.4 to - 6.7	- 6.6 to - 3.9	- 3.8 to - 1.2	- 1.1 to + 1.6	+ 1.7 to + 4.4

The following plan shows the climatic regions of Germany and shows that there are four climatic regions in Germany beginning from zone 5 to zone 8.

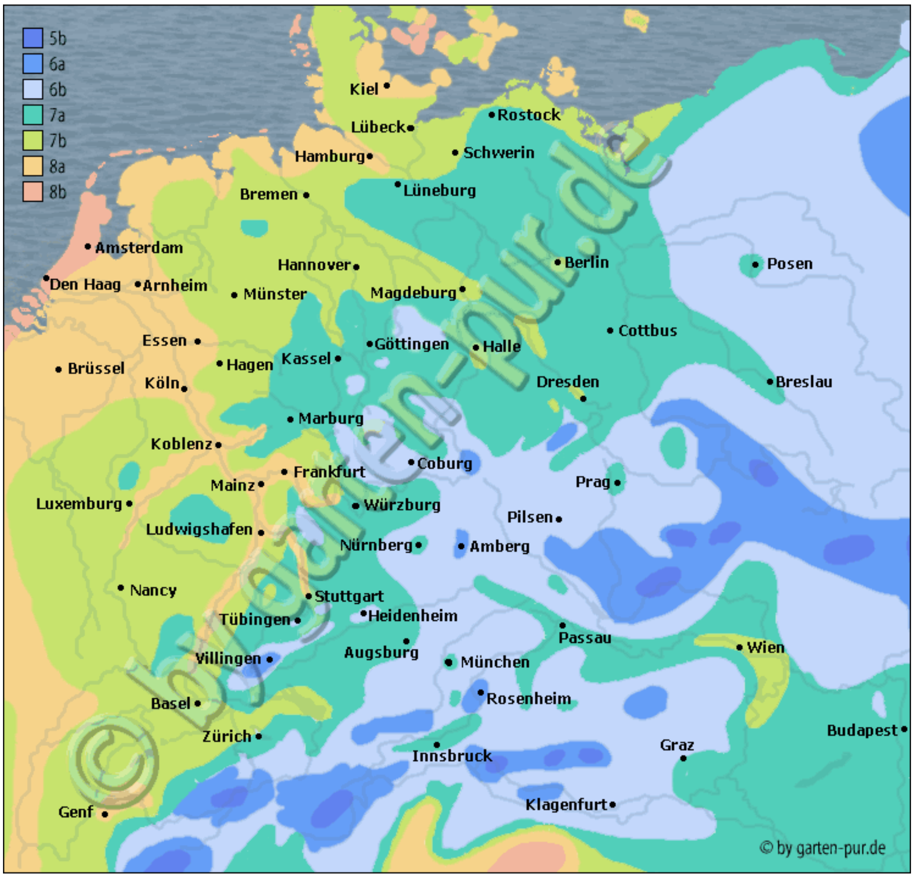


Figure 71: Climatic regions of Germany, Source: Bernhard 12.8.2004

The following plan also shows the annual average air temperature in Germany.

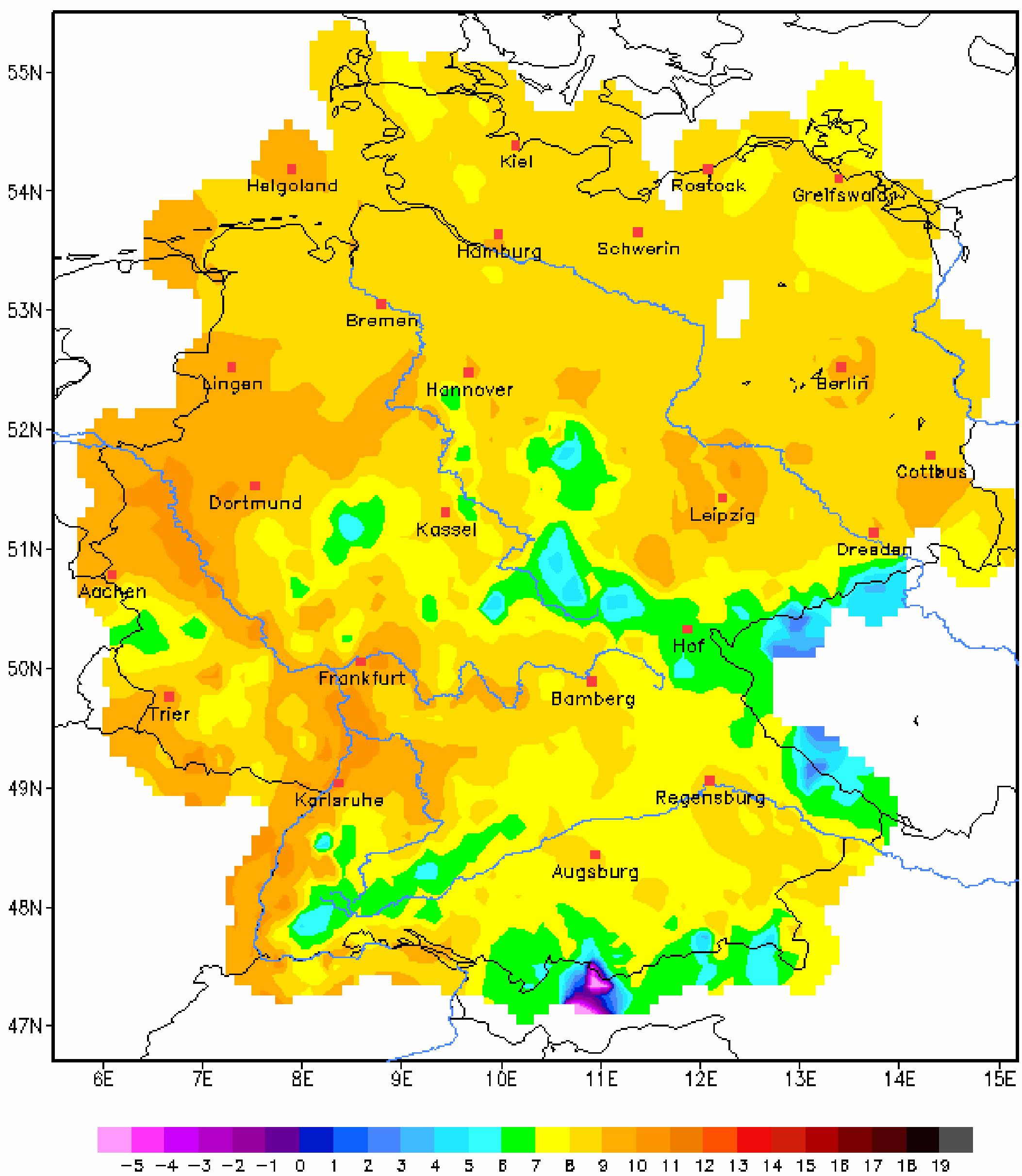


Figure 72: Annual average air temperature in Germany (1961-1990), Source: Klimadiagramme weltweit 01.01.2008b

The following plan shows the average air temperature in Germany in January.

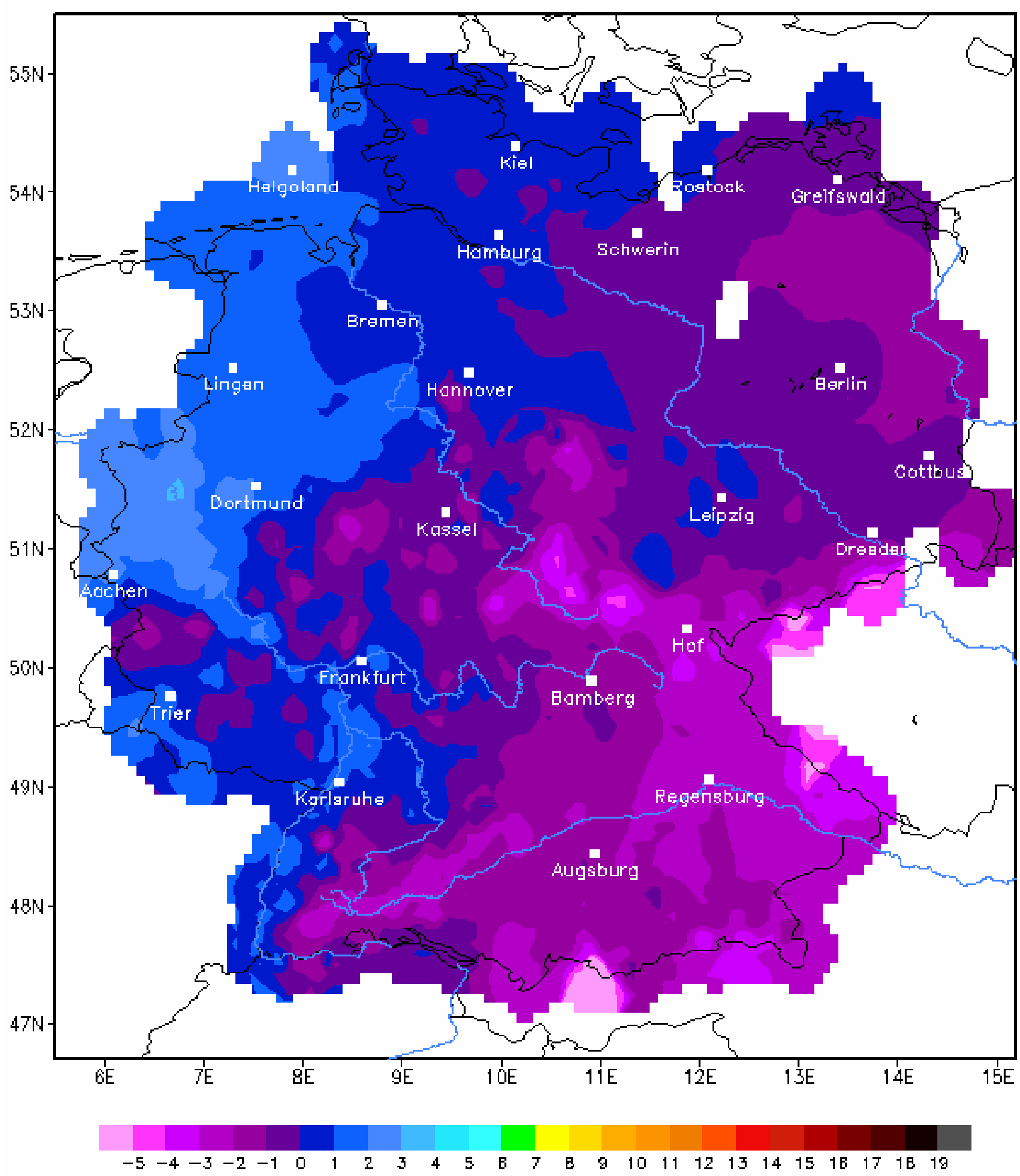


Figure 73: Average air temperature in Germany in January (1961-1990), Source: Klimadiagramme weltweit 01.01.2008c

The following plan shows the average air temperature in Germany in July as well. The maximum average temperature in the cities of Germany in July is 19.4°C in Freiburg (Diercke and Mayer 1981, Map III-VI).

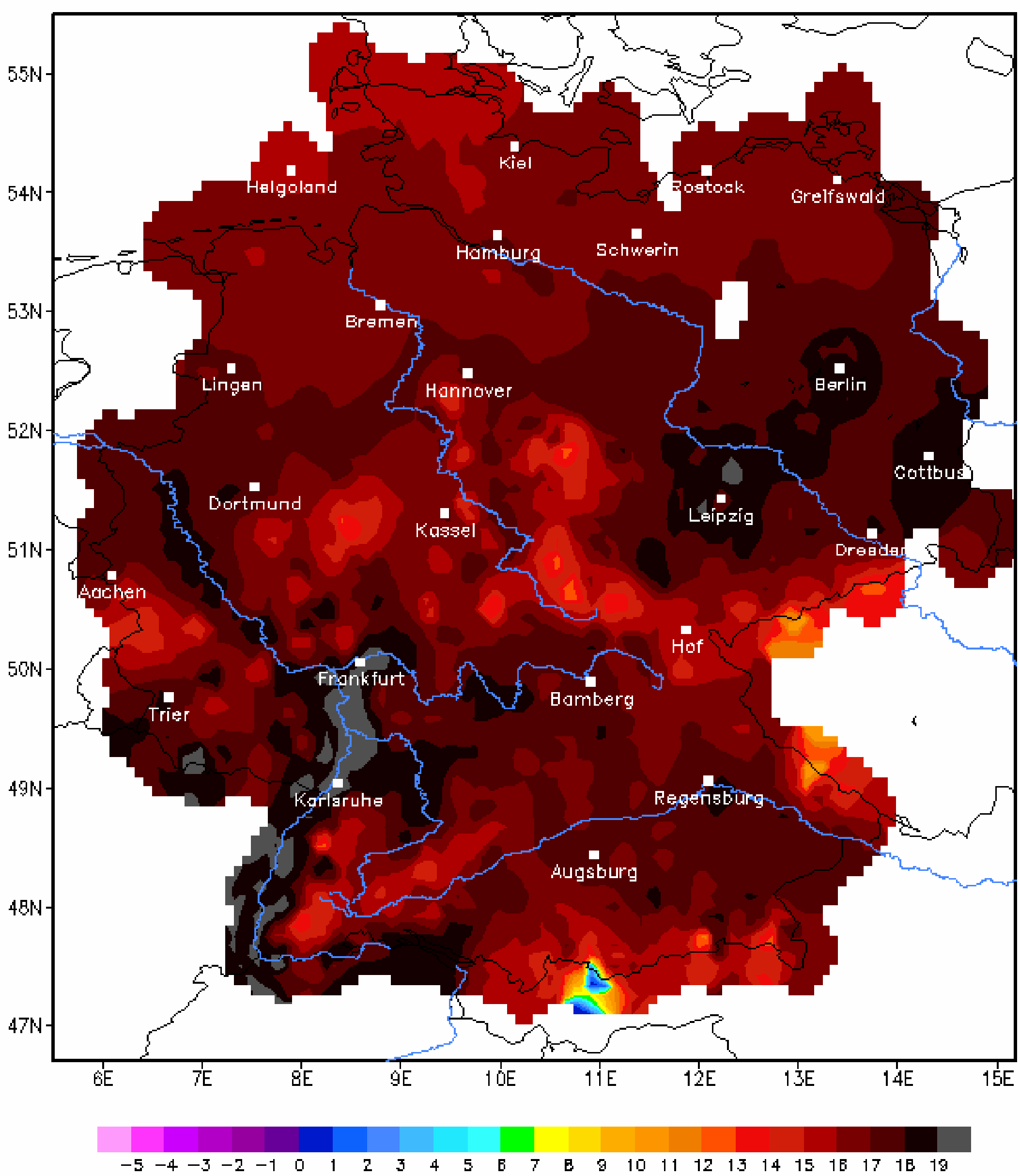


Figure 74: Average air temperature in Germany in July (1961-1990), Source: Klimadiagramme weltweit 01.01.2008d

Solar Radiation

The annual average solar radiation in Germany differs from 940 to 1200kWh/m² and in the city of Munich is from 1120 to 1140kWh/m².

The amount of solar radiation in Germany is stated in following plan. It shows the amount of solar radiation in the south of Germany is greater than in the north.

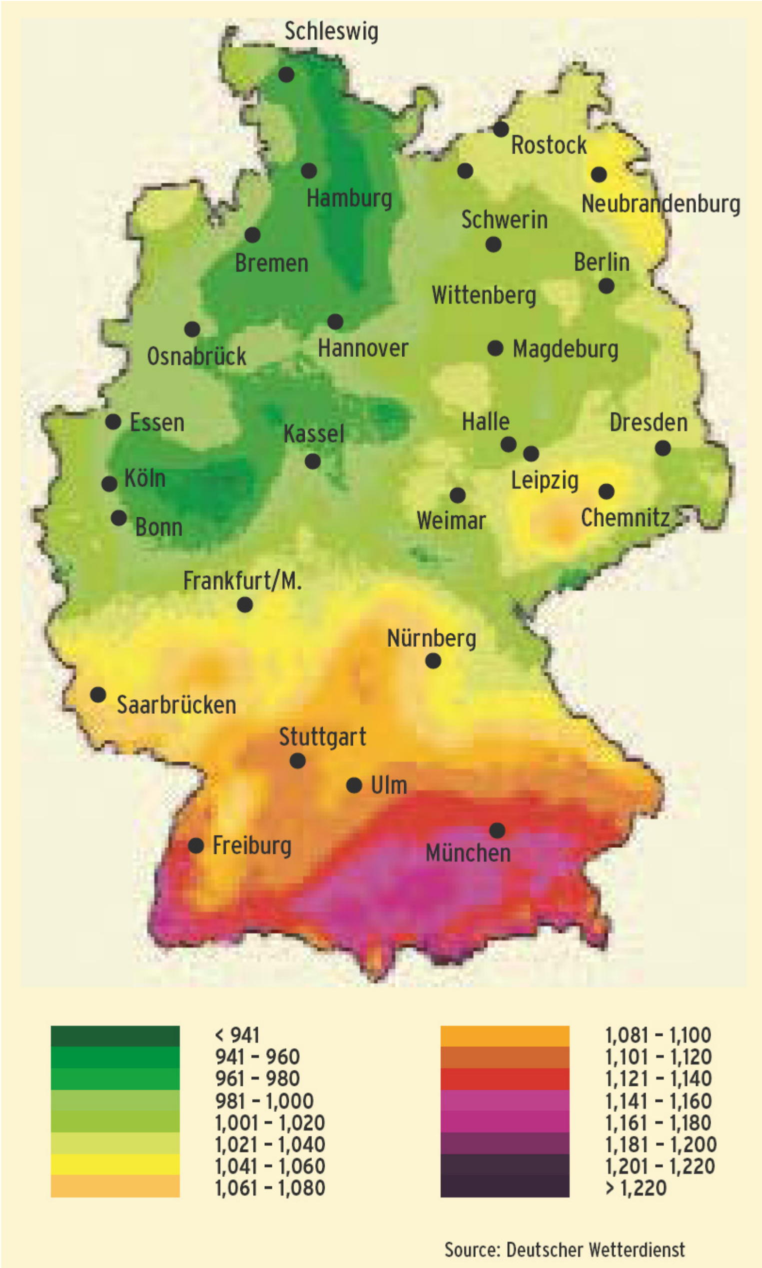


Figure 75: Annual average solar radiation in Germany (kWh/m²), Source: BMU 2006, p.68

The following plan shows the average annual hours of sunshine in Germany. The annual duration of sunshine in the northeast and south is more than the middle and west areas of Germany.

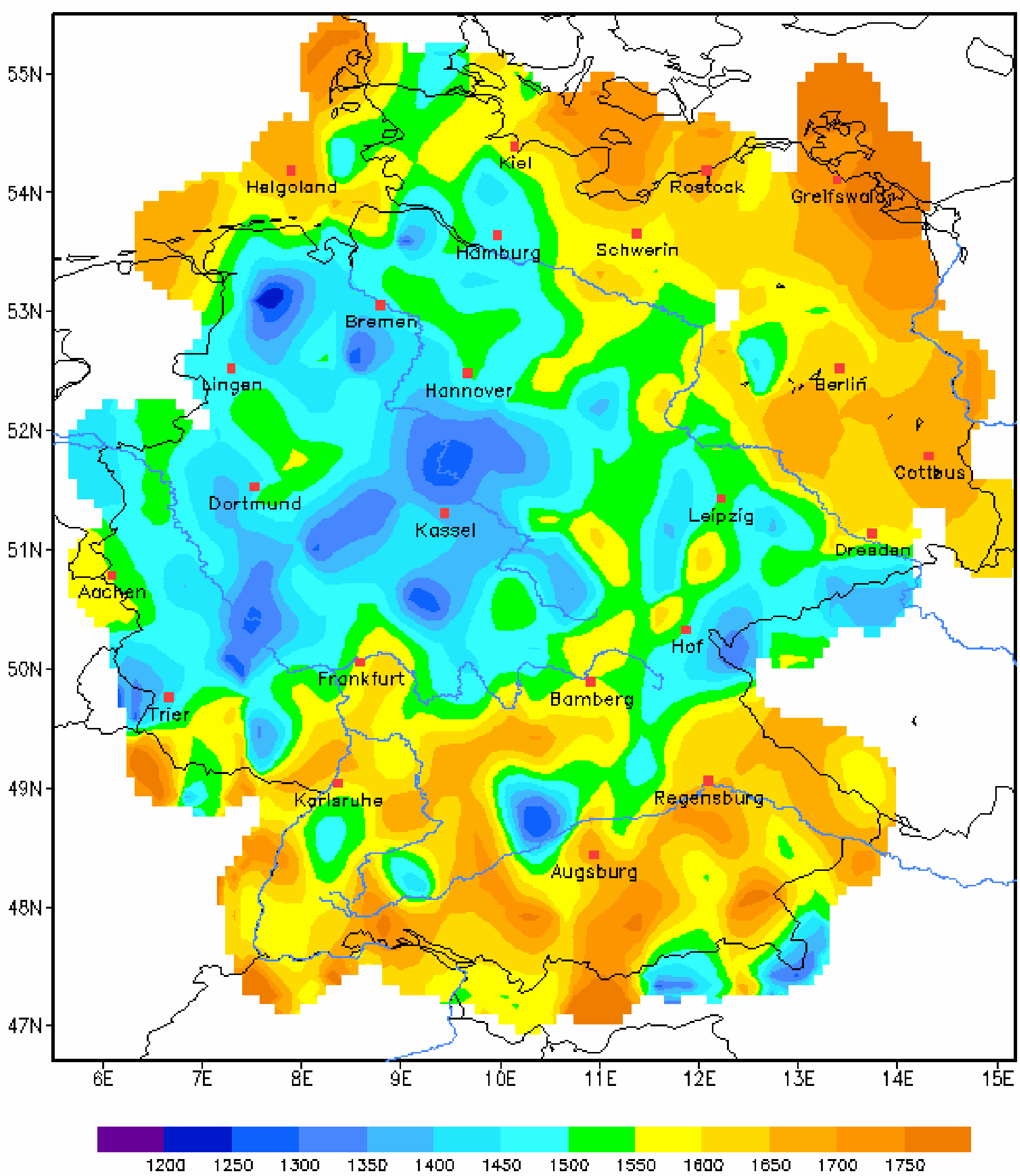


Figure 76: Average annual sunshine hours in Germany (h) (1961-1990), Source: Klimadiagramme weltweit 01.01.2008f

Precipitation

The following plan shows the annual average precipitation in Germany. Based on this plan, the east of Germany has less precipitation in comparison with the west and especially south of Germany.

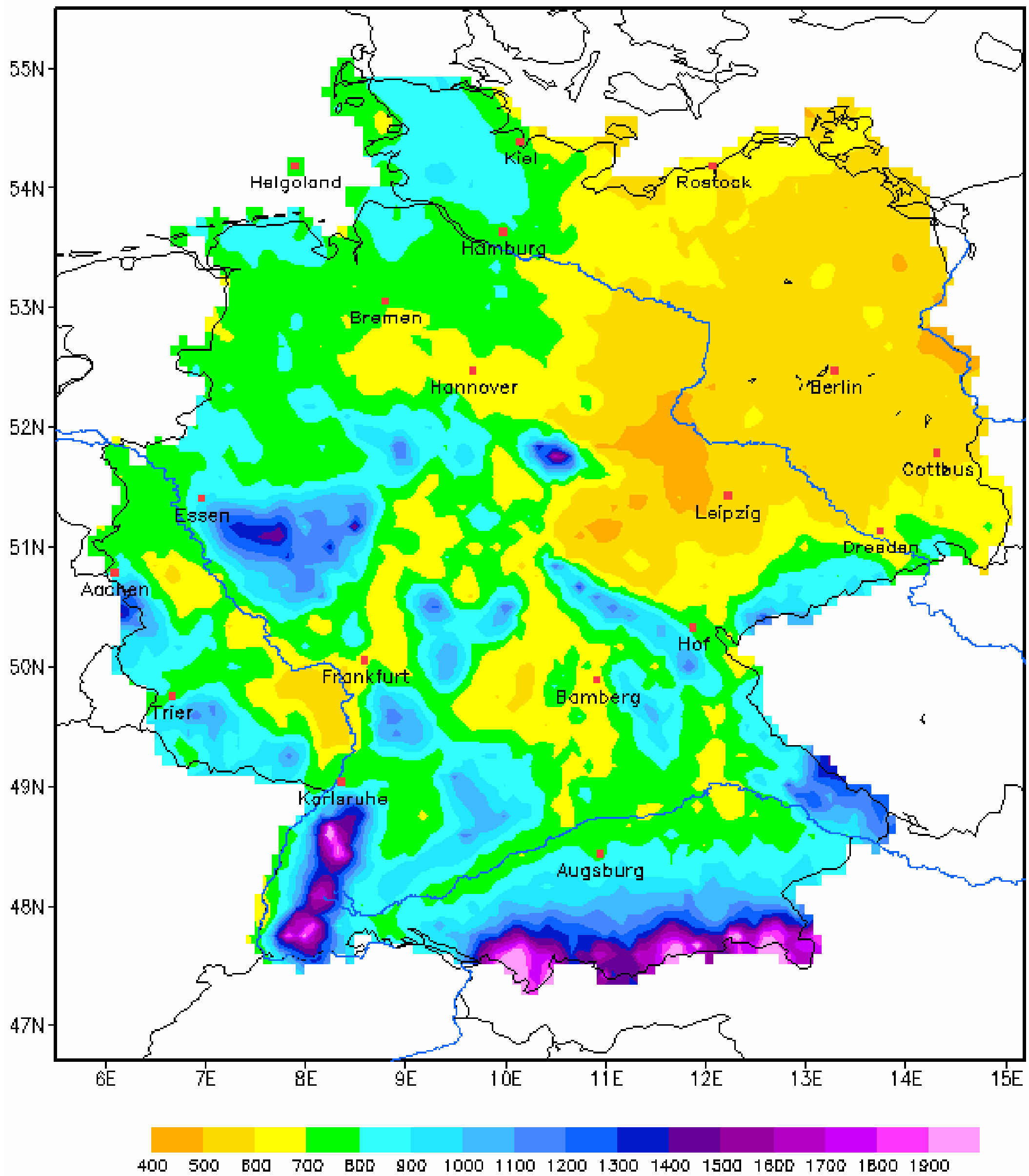


Figure 77: Annual average precipitation in Germany (1961-1990), Source: Klimadiagramme weltweit 01.01.2008e

Climate of Munich

Munich is located in an almost mountainous region and has a continental climate with cold winter and warm summer. The cold climatic region of Iran (the research area) and Tabriz also have a continental climate and from this viewpoint, Munich is comparable with Tabriz. The climatic data of Munich is also more accessible compared to other cities of Germany. Therefore, between the cities of Germany, Munich is used to be compared with Tabriz.

Based on the Köppen classification the city of Munich has a "Dfb" Climate type and a moist continental climate with warm summers, cold winters and no dry season. On the basis of ASHRAE Standards (90.1-2004 and 90.2-2004 Climate Zone), this city has "5A" climate type with cool, humid and humid continental (warm summer) climate. The latitude, longitude, elevation, annual heating and cooling degree days of Munich are mentioned as follows.

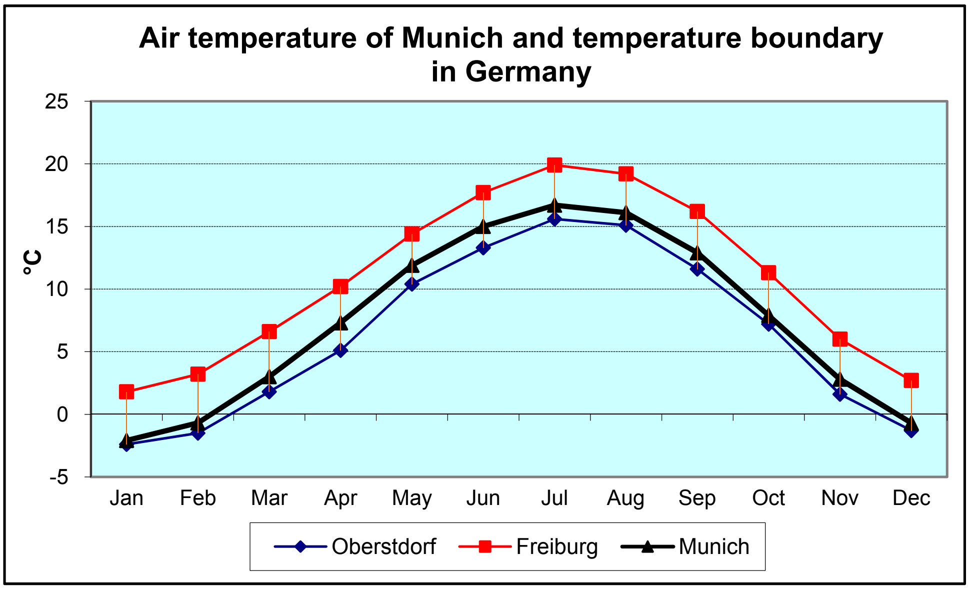
Table 16: General climate information of Munich, Source: Based on data from U.S. Department of Energy 08.08.2008c

Latitude	Longitude	Elevation	Heating degree day	Cooling degree day
48.13 N	11.70 E	520.0 m	3738	78

Climatic Parameters of Munich (Climatic Data)

Air Temperature

Based on annual average temperature, the warmest cities of Germany are Heidelberg, Stuttgart-Neckartal and Freiburg[1] in Baden-Württemberg and the coldest cities are Kempten, Oberstdorf and Fuessen[2] in Bayern (Mühr 21.04.2008). This graph shows the average dry-bulb temperature of the coldest and warmest cities of Germany as Germany's temperature boundary, and also the air temperature of Munich. The average air temperature of Munich differs from -2.1 to 16.7°C between January and July.



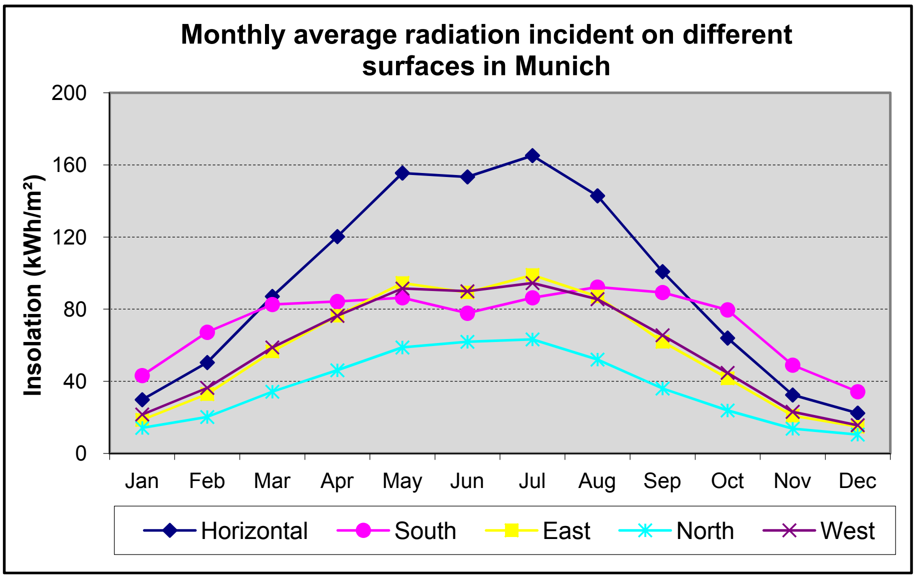
Source: Based on Data from Klimadiagramme weltweit 01.01.2008a

Comparison of Surfaces with Different Orientations

The following diagram shows the amount of insolation received by surfaces with different orientations during different months in Munich. It shows that the solar insolation received at each orientation even for the south is less in winter

[1] - The annual average air temperature of Heidelberg, Stuttgart-Neckartal and Freiburg are respectively 10.6, 10.6 and 10.8 °C (Klimadiagramme weltweit, 07.01.2008).
[2] - The annual average air temperature of Kempten and Oberstdorf are respectively 6.9 and 6.4°C (Klimadiagramme weltweit, 07.01.2008).

than in summer. South-facing surfaces receive more solar energy in cold months, when it is needed, in comparison to other orientations.

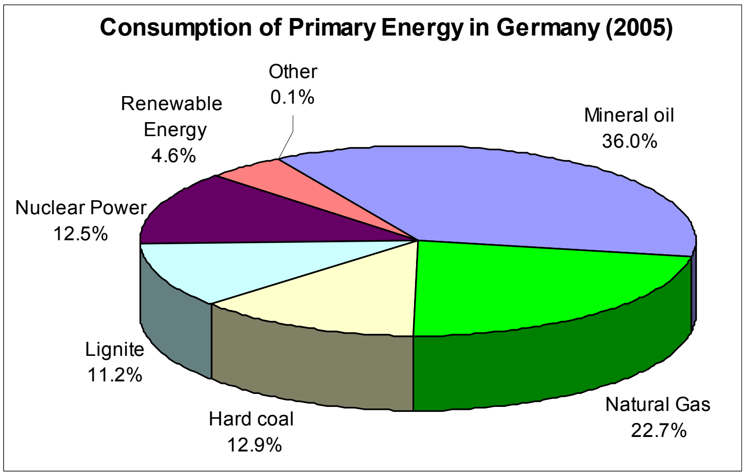


Source: Based on data from NASA 27.07.2006

Energy

Energy Consumption

The primary energy consumption of Germany in 2005 was about 14,238 petajoule (PJ) (tagesschau.de 2007b 09.01.2007b). The ratio of every energy source is shown in the following graph and table:



Source: BMU 2006, p.37 (my graphing)

Mineral oil, natural gas, hard coal and nuclear energy respectively were the main energy sources of Germany in 2005.

Table 17: The ratio of primary energy in 2005, Source: Based on data from BMU 2006, p.37

	Mineral oil	Natural Gas	Hard coal	Nuclear energy	Brown coal	Renewable Energy	Other
Germany	36.0%	22.7%	12.9%	12.5%	11.2%	4.6%	0.1%

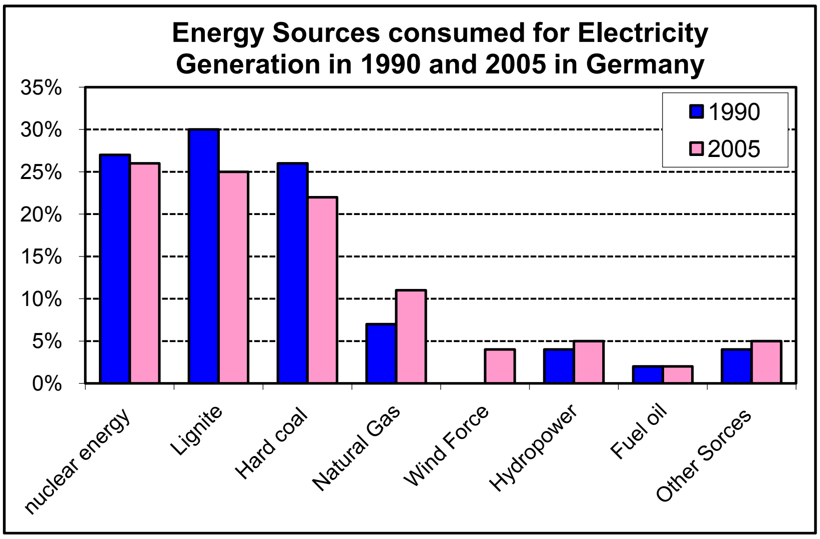
Electricity Generation

During the last 15 years, the German electricity generation has been displaced. The use of hard and brown coal and nuclear energy for the generation of electricity has decreased. Conversely, the use of natural gas, water power and especially wind force has increased. The table below shows the ratio of energy sources for electricity generation between 1990 and 2005.

Table 18: The ratio of energy sources consumed for electricity generation in 1990 and 2005, Source: tagesschau.de 09.01.2007b

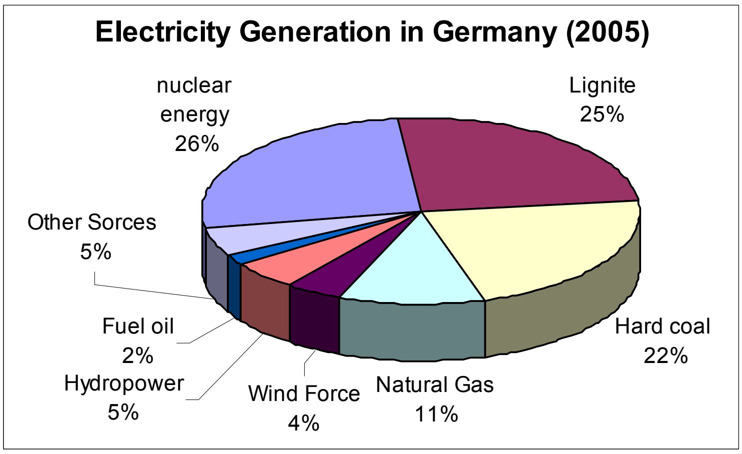
Year	Nuclear Energy	Brown coal	Hard coal	Natural Gas	Wind Force	Water Power	Fuel oil	Other Source of Energy
1990	27%	30%	26%	7%		4%	2%	4%
2005	26%	25%	22%	11%	4%	5%	2%	5%

The following graph is also to give an illustrative idea to the reader of the sources for electricity generation between 1990 and 2005 in Germany.



Source: Based on data from tagesschau.de 09.01.2007b

The following graph represents the ratio of energy sources for electricity generation. Nuclear energy, brown coal, hard coal and natural gas are respectively the main sources of electricity generation in 2005.



Source: tagesschau.de 09.01.2007b

Energy Import

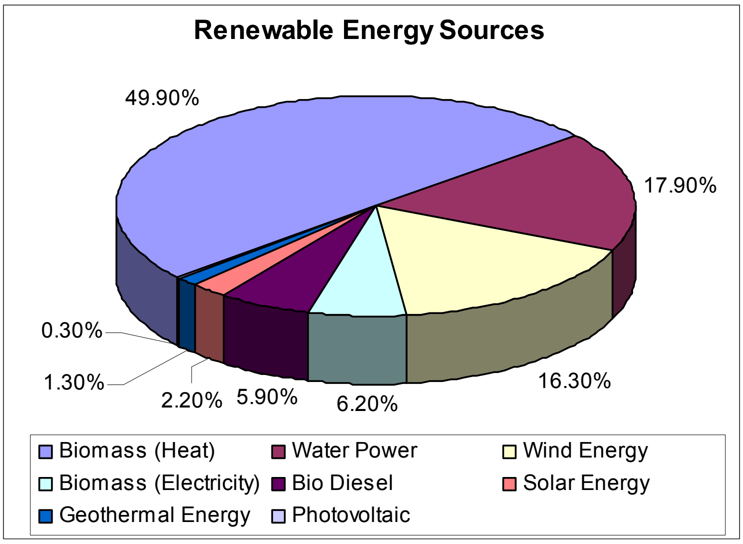
The majority of the energy consumed in Germany is imported in the form of different products excluding brown coal. The following table states the ratio of energy imports of Germany in 2004 (tagesschau.de 10.01.2007a).

Table 19: Energy source imports of Germany in 2004 (Percent), Source: tagesschau.de 10.01.2007a

Energy source	Uranium	Mineral Oil	Natural Gas	Hard Coal	Brown Coal
Share of import	100%	96.1%	83.2%	80.7%	-0.7%

Renewable Energy

The following graph represents the proportion of different renewable energy sources. Today, like earlier, approximately half of the renewable energy sources belong to biomass. The second most commonly used renewable energy is water power, which is the oldest regenerative form of energy production. Following this, wind energy is the third place. All other renewable energy sources such as bio diesel, solar energy, photovoltaic and geothermal energy are less than 10% of renewable energy production.



The Ratio of Energy Production from Renewable Sources in 2003, Source: Based on Data from tagesschau.de 15.03.2006

Building

Normal Buildings

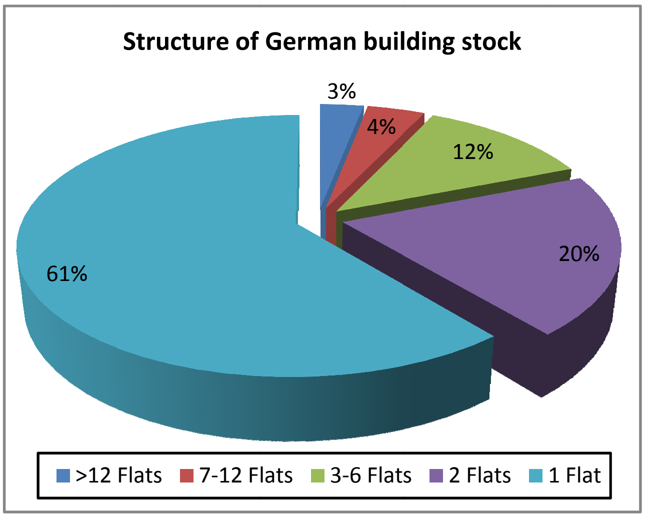
The whole German housing stock before 1990 is divided into 5 'use classes' and 6 'age classes' according to the available statistical categories. For these age-use classes the floor space of the housing is stated in this table (Kohler et al. 1999, p.3).

Table 20: Floor space per age-use class of the German housing stock before 1990 (Million m²), Source: Kohler et al. 1999, p.3

	Age class	<1870	-1918	-1948	-1965	-1978	-1990	Total
Use Class	Detached family house	105.4	168.55	159.27	276.42	252.83	195.59	1158
	Terraced house	12.69	20.31	50	87.48	108.55	56	335
	Small apartment Building	74.58	119.32	124.93	260.91	194.75	115.7	890
	Large apartment Building	16.89	27.02	12	47.27	92.57	45.36	241
	High apartment Building	-	-	-	10.18	36.09	5.63	52

The majority of the building stock of Germany was built between 1949 and 1978 and it can be assumed that energy efficient building construction was not yet on the agenda, or rather during the first years of this period it was just not possible given the historic events (Grether 2004, p.1). Therefore the energy consumption of these buildings is high.

The following graph shows the ratio of German building stock with different number of flats. Most of the buildings (61%) have only one flat and about 20% of the buildings have two flats.



Source: Sager 2005, p.12 (my graphing)

This table shows the number of buildings with different number of flats. There are about 10.7 million residential buildings with one flat.

Table 21: Number of German residential building stock, Source: Sager 2005, p.12

Residential Buildings	> 12 flats	7-12 Flats	3-6 Flats	2 Flats	1 Flat	Total
No. (Million)	0.3	0.7	2.2	3.5	10.7	17.1

Energy consumption of current German building stock is about 250kWh/m²a (Steffan 2006) and new construction in Germany about 60kWh/m²a (TU Darmstadt 2007).

Low Energy Houses

Low energy house[1] is a German building energy standard defined using the amount of annual energy demand. The energy demand of a low energy house must not exceed the following amounts for three different building types:

- One family houses: 70kWh/m²a
- Row Houses: 65kWh/m²a
- More family houses: 55kWh/m²a (Feist 1997, p.159, Loga 2002, p.14).

Low energy house is also defined based on the U-value of construction elements.

The Low Energy Standards recommend a maximum real U-value of less than 0.15 – 0.20 W/m²K for the roof, 0.20 – 0.30 W/m²K in the external walls, 0.30 – 0.40 W/m²K for building elements around the cellar and earth, and 1.5 W/m²K for windows (Schrode 1996, p.12). Air leakage of low energy houses must be also less than 3ac/h at pressure of 50 Pa (Olivier et al. 2001, p.15). Whole-house mechanical exhaust-only ventilation is also needed to ensure adequate air quality.

Table 22: Rules of low energy houses, Source: Based on data from Schrode 1996, p.12, Oberländer et al. 1997, p.26, Olivier et al. 2001, p.15

Factor	U-value
Roof	0.15 – 0.20 W/m²K
External Wall	0.20 – 0.30 W/m²K
Ground Floor above the cellar and earth	0.30 – 0.40 W/m²K
Window	1.50 W/m²K
Air Change (50 Pa)	<3 ac/h

The reduced energy demand for low energy houses can be reached through some or all of the following factors:

- Well insulated thermal envelope (Walls, roofs, windows and external doors)
- Reducing thermal bridges
- Compact building form
- Air tight outside envelope

[1] - Niedrigenergiehaus.

- Controlled air change with or without mechanical ventilation (with or without heat recovery)
- Optimum passive use of solar energy through windows
- Efficient use of electricity (low energy household appliances)
- Orientation of day spaces to the south
- Energy efficient heating systems and domestic hot water boiler
- Well informed users

The first Low Energy House of Germany was built as an experiment in the state of Hessen in 1986. As Olivier et al. (2001, p.15) say, with no excuses left to the industry for not meeting Low Energy standard in new homes, in January 2002 the federal government legislation inserted this standard into the German Building Code.

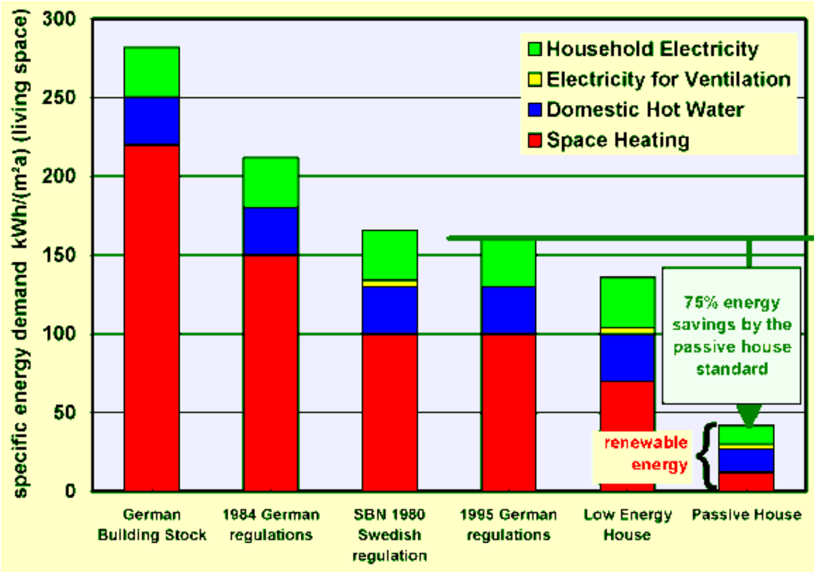
Passive Houses

Passive houses are buildings in which a comfortable interior climate can be maintained nearly without active heating and cooling systems. The house heats and cools itself, hence "passive" (Friemert and Beckmannshagen 2004, p.71). They ensure a comfortable indoor climate in summer and in winter without needing a conventional cooling and heating system. To permit this, it is essential that the building's annual demand for space heating does not exceed 15kWh/m² year. The minimal heat requirement can be supplied by heating the supply air in the ventilation system - a system, which is necessary in any case (Scandinavian Homes Ltd. 16.07.2008).

The existing air supply system for transporting the needed heat makes a redundancy of the installation of a separate heating system; because the standard of the passive house heat consumption of 15kWh/m²a is a result of the basic economic consideration.

"The standard of the passive house heat consumption of 15kWh/m²a is a result of the basic economic consideration that the installation of the separate heating system is unnecessary, due to the existing air supply system, which transports the required heat. The insignificant heat loss through ventilation is almost completely compensated by free "passive" energy contribution" (Austrotherm 15.03.2008). In a Passive House, thermal comfort (ISO 7730) can be achieved solely by postheating or postcooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions (DIN 1946) - without the need to recirculate air (Feist 23.09.2006c).

The Passive House is the world's leading standard in energy efficient construction: the energy saved on heating is 80% compared to conventional standards. They are cost-efficient, high quality, healthy and sustainable construction (Feist 10.02.2008).



Comparison of different building energy consumption, Source: Feist 25.12.2005

Two principles of cost-efficient passive houses are: (1) to reduce heat loss and, (2) to optimise passive solar heat gain (Feist 2001, pp.10-11). In passive houses, the heat loss is significantly reduced and passive solar heat gain through windows is so efficiently used that the buildings need no separate heating system. Passive houses do not differ significantly from standard new construction. They only include improvements in the construction such as more insulation, better windows, high air tightness and heat recovery from exhaust air. "The conception of passive houses was developed in the late eighties" (International Energy Agency 2001b, p.2) and the first passive house of Germany was built in 1991 in Darmstadt-Kranichstein (Graf 2003, p.6).

Heat Loss

"Heating" is always the substitution of energy losses and therefore heating energy consumption can be reduced to an arbitrary low amount by effectively minimising losses. The passive house concept is based on the reduction of the heat losses (Jolly 2006, p.51). In passive houses, energy loss and thus the need for heating energy is very little. A building loses its heating energy through the external envelope via conduction, radiation and infiltration. The building envelope consists of walls, roofs, floor, windows and external doors. The heat loss via the walls, roof and floor will be minimised by reducing U-values through the use of insulation. The windows consist of window frames and glass therefore, to reduce heat loss through windows both the window frame and glass must have a small U-value.

The techniques for reducing heat loss within a passive house include:

1. Thermal insulation of building envelope (walls, roof and floor)
2. Reducing thermal bridges
3. Airtightness of building envelope

4. Use of proper passive house windows
5. Use of air heat recovery system (Feist 2001, p.11)

Insulation

To achieve very little heat loss through external envelope in passive houses, the envelope must be highly insulated. Therefore, the most important characteristic of a passive house is a highly insulated external envelope.

In a passive home, the entire building envelope has excellent thermal insulation. The envelope consists of all parts of the construction which separate the indoor climate from the outdoor climate (Ecolodge 2008, p.3).

As a consequence of having high insulated envelope, the transmission heat losses during the cold season are negligible. Another consequence is that the temperatures of the internal surfaces are almost the same as the indoor air temperature. This leads to a very comfortable indoor climate and avoids damages caused by the humidity of indoor air (Feist 23.09.2006e). In a well insulated building, the inner surfaces of walls, roof, and floor are not cold; and do not thus have cold radiation (Graf 2003, p.27). As well, when touched, they do not have uncomforting effects.

In a passive house, conventional insulation material can be used. The thickness of insulation material must be calculated so that the U-value of the building envelope is equal or less than $0.15 W/m^2K$ (Berndgen-Kaiser 2004, p.17). The thickness of insulation in a passive house differs from 25 to 40cm depending on the type of insulation material and building structure (Graf 2000, p.11, Graf 2003, p.12). From the viewpoint of conservation (environmental protection), the insulation material must be recyclable and contain no harmful substances which cause pollution.

Thermal Bridge

Heat will flow the easiest path from the heated space to the outside - the path with the least resistance. And this will not necessarily be the path upright to the surfaces. Very often, heat will “short circuit” through an element, which is more highly conductive than the surrounding material. The experts call a case like this a “thermal bridge” (Feist 23.09.2006d).

Typical effects of thermal bridges are:

1. Decreased interior surface temperatures; in the worst cases this can result in high humidity in parts of the construction
2. Significantly increased heat losses.

If the thermal bridge coefficient (which is an indicator of the extra heat losses of a thermal bridge) is lower than 0.01W/mK, the detail is said to be “Thermal Bridge Free” (Feist 23.09.2006d). Passive houses must be thermal bridge free. To have no thermal bridge, the insulation must be applied continuously around the building envelope and must be closed without any breakage.

"By this method there will be no cold spots and no increased heat losses. This is a contribution to high quality, comfortable, and long lasting construction, too" (Feist 23.09.2006e). Being thermal bridge free is not only essential for heat loss, but also to avoid dew, water and mold (Graf 2003, p.16).

Four rules for reducing heat loss through thermal bridging are:

- Avoiding rule: where possible, the insulation envelope must not be cut.
- Break through rule: if it is not possible to avoid insulation breakage, the heat resistance must be increased at the insulation surface. For example, aerated concrete or wood must be used in this place.
- Connection rule: Insulation layer at the end of building component connection must overlap and must be connected throughout the entire surface.
- Geometry rule: The edges must be chosen with obtuse angles (Feist 2001, p.17).

Air Tightness

Heating energy of a house can be lost via infiltration through the building envelope via elements such as walls, roof, floor, windows, external doors and also from the connection between envelope components. In order to be energy efficient, the external envelope of a house has to be airtight so as not to lose heat from infiltration between inside and outside.

The envelope of the passive house must be airtight to avoid heat loss. With airtightness, damages to the buildings such as mold will be avoided, sound transmission is reduced, and the air quality improves (Graf 2000, p.14).

Excellent airtightness of the building envelope is a crucial precondition for passive houses (Feist et al. 2001, p.46). Many construction details had to be revised to fulfil the augmented specifications, e.g. flash strips to join up window-frames to the wall are necessary (International Energy Agency 2001a, p.2).

Insulation materials are not generally airtight (with the exception of foam glass) and a well-insulated construction is not necessarily airtight. Air can easily pass through insulation made from coconut, mineral or glass wool. These materials have excellent insulation properties, but are not airtight. Therefore, the airtight envelope has to be designed and built separately (Feist 23.09.2006b). For the majority of timber construction wooden composite boards are used (taped at the joints), and in masonry construction a continuous inside plastering is sufficient. It is important, that the airtight envelope is continuous, without interruptions. This is particularly important at joints (Jolly 2006, p.16).

"On the other hand an airtight construction is not necessarily well insulated: e.g. a single aluminum foil can achieve excellent air tightness, but has no relevant insulation property" (Feist 23.09.2006b). Both insulation and airtightness are essential characteristics of a high quality building envelope, but in most cases both have to be achieved independently.

"Further, achieving air tightness should not be mistaken with the function of a "vapour barrier". Conventional room plastering (gypsum or lime plaster, cement plaster or reinforced clay plaster) is sufficiently airtight, but allows vapour diffusion" (Feist 23.09.2006b).

To have an airtight building, the building components must be connected to each other very tightly. There must be no permeable aperture and infiltration through windows must be avoided.

The air change rate of a passive house at a pressure of 50 Pa must be equal or less than n50=0.6ac/h. "Sören Peper, a scientist at the Passive House Institute, proved by a systematic field study that n50 leakage rates between 0.2 and 0.6 h^{-1} can reproducibly be achieved today" (Feist 23.09.2006b).

Blower Door Test

The air leakage and airtightness of passive houses can be checked using the "blower door test".

The easiest way to measure the air tightness of a house is with a diagnostic tool called a blower door (Nelson et al. 07.03.2008). The blower door consists of a powerful, calibrated fan that is temporarily sealed into an exterior doorway. The fan blows air out of the house to create a slight pressure difference between inside and outside. This pressure difference forces air through all holes and penetrations in the exterior envelope (Krigger 2002, p.75). Blower door tests are typically performed at a pressure difference of 50 Pa (0.2 inches of water column) (CGE Solution 15.06.2008).

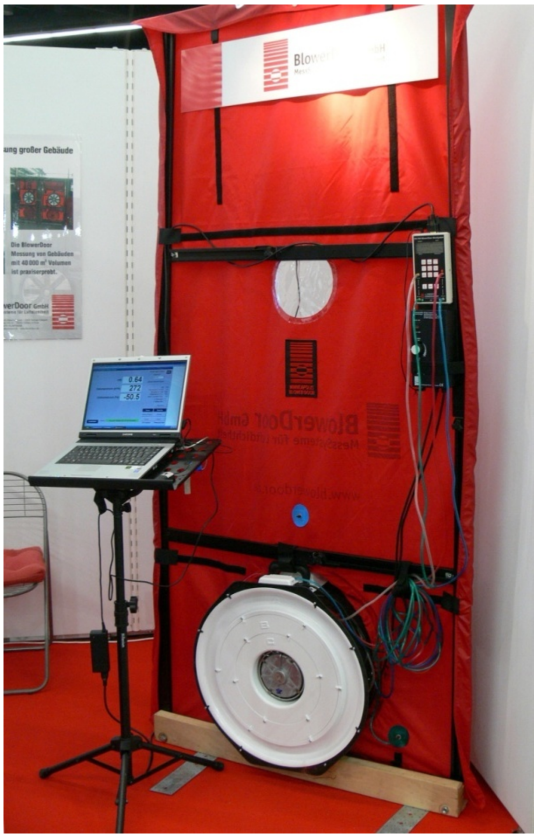


Figure 78: Blower door test

Air Change with Ventilation Systems

"From experience (and DIN 1946) we know, that 30 m³/h is a minimum air rate per person to maintain a reasonable indoor air quality" (Feist 23.09.2006c). But contemporary constructions, especially passive houses (with maximal 0.6 air change per hour), are quite airtight; therefore the air change from infiltration can not be enough. Ventilating, by opening apertures, is not a convincing strategy either.

The air change through apertures differs with wind pressure and temperature buoyancy over a large area. In permeable buildings, in which wind blows moderately, the air change is not enough in the calm and mild weather periods (Feist 2001, p.20).

Occupant health and comfort are the most important objectives of all buildings such as passive houses and to achieve it, an excellent indoor air quality is indispensable. "Getting a sufficient volume of fresh air is not just a question of comfort, but a requirement for healthy living conditions. Therefore mechanical ventilation is the key technology for all new construction as well as refurbishment of existing buildings. In all passive houses thus a mechanical ventilation system must be used for air change of building" (Feist 19.05.2007).

It is essential for a ventilation system in a passive house to provide high quality indoor air for the following reasons: a continuous exchange of sufficient air volume has to be provided even in the cold season in any new building, and that will only work using a mechanical system (Feist 23.09.2006g).

Systematic research in dwellings has shown that for an appropriate distribution of fresh air to all rooms, and a sufficient volume of extracted air from the wet rooms, a controlled supply and exhaust air system is most suitable. Fresh air will be supplied to the living, working and sleeping rooms through a supply air valve. Similarly, in the exhaust fan ventilation system, used air is extracted from the kitchen, bathrooms and other rooms with high indoor air pollutants through extract valves. This results in cross flow ventilation in the dwelling: The fresh air will first enter the main living rooms, from where it will flow through the overflow zones, into the wet rooms. The wet rooms will have a quite high ventilation rate and, therefore, it will not take long for towels to dry. The principle of cross flow ventilation allows for optimal utilisation of fresh air. Initially it will maintain an excellent indoor air quality in the living rooms, and then remove stale air from the overflow zones (e.g. from the wardrobe in the hall) and finally it will dehumidify the air in the wet rooms (Feist 23.09.2006g).

One advantage of ventilation systems is the high interior air quality they facilitate. Carbon dioxide and other harmful substances, which escape from furniture and construction material, will be extracted from the building with the use of a ventilation system. Pollen and pollution will be filtered out of the air before it enters the building (Graf 2003, p.20). Because almost all the air in the building passes through the ventilation system, also it can be easily filtered to remove pollen and spores.

Experiments of the Free University Berlin have indicated that the endotoxin content of filtered indoor air (endotoxin escapes during bacteria destruction) is lower than this one of outdoor air. Only after using filters for more than 12 months, an increase of endotoxin was determined. This proves that a properly maintained ventilation system performs better air quality than window airing. Corresponding tests in passive houses confirm this theory.

Heat Exchanger

Due to the requirement of 30m³ of fresh air per person/hr (German Institute of Standards 1946), every hour a minimum of 30m³ of warm indoor air must be exchanged with an equal amount of cold outdoor air to supply this demand. Therefore, a significant amount of energy must be consumed to increase the temperature of cold outdoor air to indoor air, during winter. If however, the heat of exhaust air is used for heating the fresh air, the energy consumption of a building can be effectively reduced. Passive houses are well-sealed buildings and therefore, all the air exchange for ventilation takes place via the ventilation system. It is thus possible to use the heat from the exhaust air for heating the incoming air. An air-to-air heat exchanger can be used to exchange the heat of exhaust and supply fresh air.

"Passive Houses have a continuous supply of fresh air, optimized to ensure occupant comfort. The flow is regulated to deliver precisely the quantity required for excellent indoor air quality. A high performance heat exchanger is used to transfer the heat contained in the vented indoor air to the incoming fresh air. The two air flows are not mixed" (German Eco House 14.07.2008).

Waste air is extracted from the bathroom, WC and kitchen and passes through a heat exchanger, which removes and stores its warmth before releasing it. If necessary, this warmth is used to heat the incoming fresh air that is constantly fed into the living rooms. A built-in filter keeps the ventilation conduit and heat exchanger clean (Eckert et al. 2000, p.80).

A counterflow heat exchanger works as follows: the warm air (red, extract air) flows through a channel and delivers heat to the plates. This air will leave the exchanger cooled (orange, then called 'exhaust air'). On the opposite side of the exchanger plates, the 'fresh air' (blue) flows in separate channels. This air will absorb the heat and will leave the exchanger with a higher temperature (but still, unpolluted). It is then called 'supply air' (green). The counterflow principle allows for almost 100% recovery of the temperature difference, if the exchanger is long enough. In practice, systems with 75% to 95% are available (Feist 23.09.2006h).

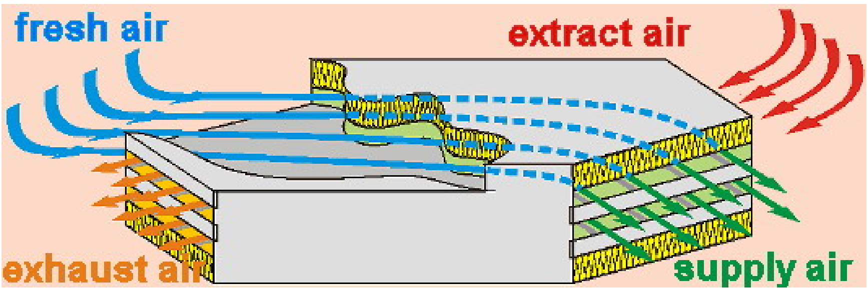
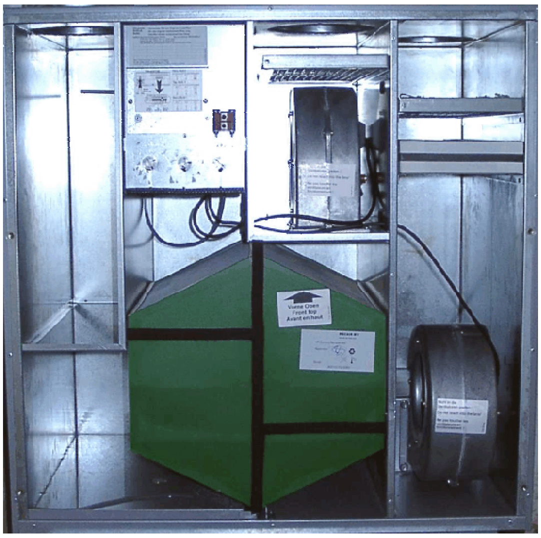


Figure 79: Heat exchanger, Source: Feist 23.09.2006h

In dwellings in Central Europe, the ventilation heat loss with an appropriate air change rate will be between 20 and 30kWh/m²a. Compared to all other heat flows in an energy efficient house this is a significant value, in fact, it is more than the overall heat requirement in a typical passive house. There are currently heat exchangers available that achieve a 75 to 95% recovery rate for these heat losses. These highly efficient recovery units have been developed especially for use in passive houses. Using such an efficient heat recovery system, the remaining ventilation losses will be negligible; between 2 and 7kWh/m²a (this is a pre-condition for a passive house) (Feist 23.09.2006g). The heat recovery grade of ventilation systems in passive houses must be more than 75% (Berndgen-Kaiser 2004, p.22), and their electricity consumption should also be quite low (less than 0.40 Watt for one cubic meter air flow) (Feist 03.12.2006a).



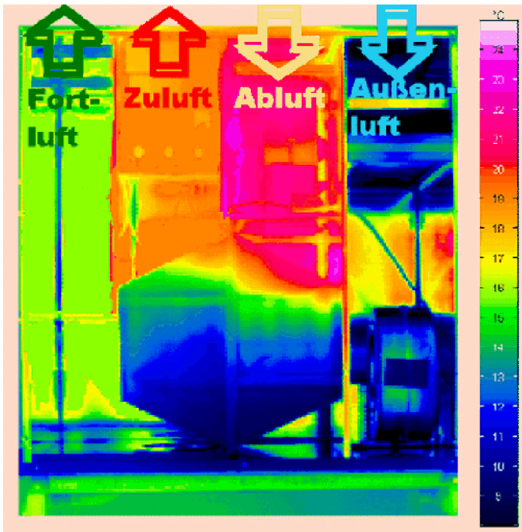


Figure 80-81: Heat exchanger, Source: Feist 23.09.2006g

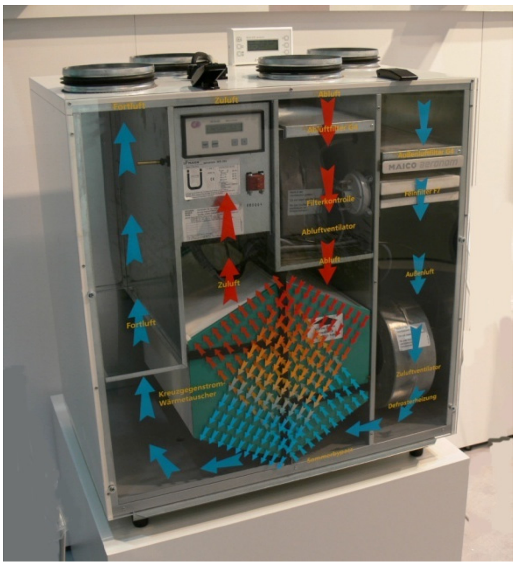


Figure 82-83: Heat exchanger

With the use of a heat exchanger ventilation system in a passive house the following objectives are achieved:

- Removal of air pollution such as carbon dioxide, endotoxin, odours, smoke and evaporation especially from spaces with more pollution such as toilet, bathroom and kitchen.
- Supplying sufficient fresh air for occupants to living spaces (living room, study room, bedroom and work room).

- Controlling the incoming air and elimination of dust, pollution, pollen, odours, etc. from entering the building.
- Heat recovery and thus energy saving with the use of a heat exchanger.

In the installation of ventilation systems, in order to avoid condensation and mold, no thermal bridge must be allowed (Berndgen-Kaiser 2004, p.21). The current heat exchangers are flat heat exchangers, counter flow heat exchangers, cross flow heat exchangers and counter flow canal heat exchangers (Graf 2000, p.19).

Subsoil Heat Exchanger

An additional opportunity to increase the efficiency of ventilation systems is the use of earth buried ducts. The ground, during winter, has a higher temperature than the outdoor air, and during the summer a lower temperature. Therefore, it is possible to preheat fresh air in an earth buried duct during winter, or to cool it in summer. This can be done directly with air ducts in the ground, or indirectly with brine circulating through pipes buried in the earth, heating or cooling the air with a water-to-air heat exchanger (Feist 23.09.2006h).

In earth heat exchangers, the fresh cold air is sucked into a 20 to 50 m long pipe system, which is buried about 1m deep in the earth under the house (Graf 2003, p.22). This cold air flows through the underground pipes, and even in the cold winter days, it gets heated by the earth to temperatures above 5°C (41°F) (Friemert and Beckmannshagen 2007, p.36), before it reaches the air-to-air heat exchanger.

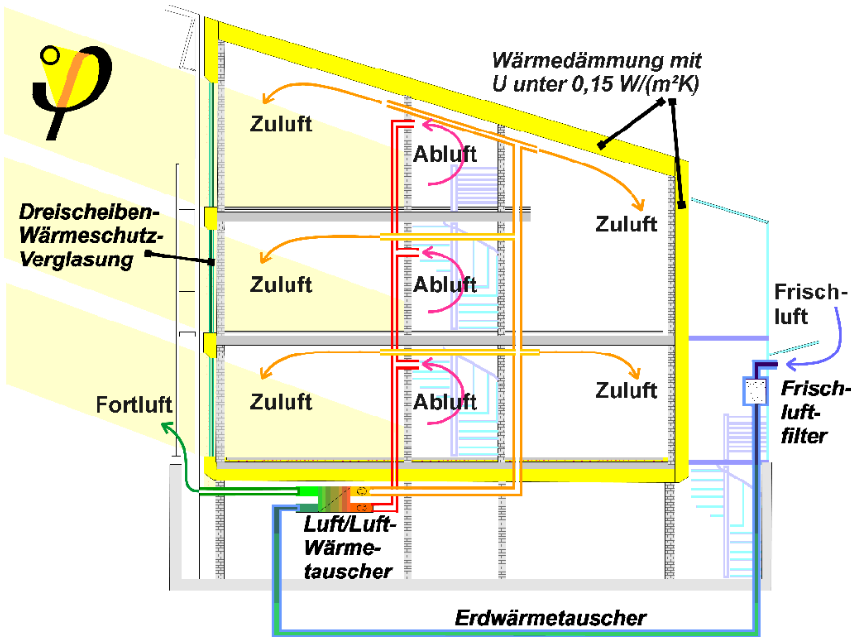


Figure 84: Ventilation system and subsoil heat exchanger in passive houses, Source: Feist 25.12.2005

It is theoretically possible that air flows through the pipes in summer too. The outside warm air becomes cool by the earth to a pleasant temperature, thus decreasing the supply air temperature and room temperature (Graf 2000, p. 20). The use of a subsoil heat exchanger for preheating the air in winter and pre-cooling it in summer will reduce the energy need for both heating and cooling.

Heating System

Due to the minimal heating requirements of passive houses, it is possible to use air as heat distributer and dispense heat via the ventilation system (Berndgen-Kaiser 2004, p.23). In a passive house there is an opportunity to heat the rooms by heating the air supplied to them. Fresh air must, in any case, be supplied to the living room, the study and sleeping rooms. Therefore, this air can be used for heat distribution as well. It is only fresh air (not recirculated air!), the mass flow is limited (to avoid dry air conditions) and the temperature is not allowed to exceed 55°C. Therefore, this type of fresh air heating will only work for buildings with a very low heat requirement, which is precisely the defining condition for a passive house. This gives the opportunity to use clever and space-saving solutions for the building's services, e.g. the ventilation compact units (Feist 23.09.2006g). During cold days, after the supply air has been preheated by the earth, it will be further heated in a ventilation plant ($160m^3/h < 55°C$) (Wortmann 2005, p.17) and then enter the room.

Windows

The windows have solar heat gain performance but can also lose a lot of energy via conduction, infiltration and radiation. Therefore, windows are an important component of passive houses. The heat loss of windows via conduction, thermal bridges, infiltration and radiation must be as little as possible and their heat gain in winter must be as high as possible.

Window Orientation

South-facing windows can collect a lot of solar heating energy in winter (and less in summer especially with the use of shading devices); therefore, a passive house must have a large amount of south-facing windows to collect solar heating during winter. The west and east-facing windows can collect a lot of heat from the sun in summer, which can cause overheating. The north-facing windows can not collect direct sunrays and thus receive little heat gain in winter. But they can lose a lot of heating energy in winter. Therefore the area of west, east and north-facing windows must be minimised.

Window Glass

The heat loss of windows via conduction will be reduced by reducing the U-factor of both window components (window glass and frame). The number of glass layers, their thickness and the kind of gas between them are important factors in thermal loss coefficients of window glass.

“The thermal loss coefficients, U_w, of such passive house windows are lower than 0.8W/m²K according to the new European standard (EN 10077)” (Feist 23.09.2006i). To achieve this thermal loss coefficient in passive houses, a triple layer of glass must be used and the space between each layer must be filled with Nobel gases (with very low heat conductivity) such as argon, krypton and xenon.

Heating energy can also be lost through radiation of heat from inside to outside the building through glasses.

To avoid thermal radiation to outside through the windows, an invisible, very thin layer of metal oxide (often silver) must be applied to one of the panes of glass (Graf 2000, p.15). “The introduction of razor-thin metal coatings inside the interpane space was the most important success - called “low-e”-layer for the low thermal emissivity. These coatings reduce the thermal radiation between the inner and the outer pane by a factor of 5 to 20” (Feist 23.09.2006j).

Solar Heat Gain of Windows

“South-facing passive houses are designed as solar houses” (Nachhaltig-Wirtschaften 11.06.2008). The passive gain of incoming solar heat through the windows will cover close to 40% of the heat losses if all guidelines are followed (Scandinavian Homes Ltd. 16.07.2008). Due to the importance of solar heating for passive houses, solar transmittance of windows must be as much as possible. Solar transmittance of window panes must be between 50 and 60% (Berndgen-Kaiser 2004, p.19) or SHGC[1]>50% to allow more than 50% of the solar radiation to enter the building for heating. The windows must also be located to eliminate shade on them during winter, as shading decreases their solar heat gain performance.

Table 23: Characteristics of window glasses, Source: Feist 2001, p.27

Glass type	Single	Double	Double Low E, Argon	Triple Low E, Krypton	Triple Low E, Argon
Ug-value (W/m²K)	5.60	2.80	1.40	0.70	0.70
Surface Temperature (°C) (-10 °C out, 20 °C in)	-1.8	9.1	14.5	17.3	17.3
Solar Transmittance (%)	0.85	0.76	0.63	0.49	0.60

[1] - Solar heat gain coefficient.

Window Frame

The heat loss of window frames via conduction will be reduced by using a window frame with a low thermal loss coefficient. Therefore for passive houses windows with an insulated frame must be used. The U-factor of window frames for passive houses must be between 0.5 and 0.9W/m²K ($0.5 \leq U_f \leq 0.9$W/m²K) (Berndgen-Kaiser 2004, p.19).

Window frames can also lose energy through infiltration, therefore, the connections between glass and window frame, and between the window leaf and frame must be airtight.

Passive House Windows

Passive houses must have the most highly efficient windows. Their U-factor (combination of glazing and frame) must be equal to or less than 0.8 ($U_w \leq 0.80$ W/m²K) (Feist 2001, pp.28-30) and their solar heat-gain coefficient must be more than 50% (Berndgen-Kaiser 2004, p.19).

The type of glazing and frames will depend on climate. In the Central European climate, there are three essentials:

- Triple glazing with two low-e coatings (or another combination of panes giving a comparable low heat loss)
- Insulating "Warm Edge" - spacers
- Super-insulated frames (wooden or plastic frames)
- Components for thermal bridge free and air tight windows (Feist 23.09.2006j)

These highly efficient windows of passive houses allow more solar heat in than the amount lost through them and therefore result in a positive energy balance (Suistainable Energy Ireland 2007, p.16). Most windows should be south-facing so that they are not shaded. As far as possible, these windows should also be fixed rather than opening, because the opening windows are not as functional in this regard as the fixed ones.

Advantages of Passive House Windows

If the outdoor air temperature is below -7.5°C (18.5°F), there will be frost on the interior surface, well known as "frost pattern". Poor insulation, therefore, is related to minimum comfort and increased risk of damages. But the advantages of the passive house window are that, not only are heat losses reduced, but also thermal comfort is increased. Even during periods of heavy frost, the interior surface temperature will not fall below 17°C (62.6°F). Consequently, no "cold radiation" can be perceived from such a window nor is an uncomfortable cold air layer possible – if no radiator exists near the window. If a passive house window is used, no temperature stack will be perceivable, therefore; a radiator can be placed at the interior walls and the optimal thermal comfort according to ASH-RAE-55 comfort class “A” will still be met” (Feist 23.09.2006j).

External Doors

External doors are a part of the building envelope and heating energy can be lost through them, therefore to reduce heat loss via conduction they must have minimal thermal loss coefficients. Heating energy can be lost through external doors via convection as well as infiltration. Therefore, the external doors must be airtight and an extra internal door swinging into the room must be added. This will reduce heat loss through the internal warm air exhausting during the use of these doors to enter into the building and exit from it.

Use of external doors in north-facing walls of a building (where it is often shaded) will increase heat loss. For this reason, the external doors must not be placed in north-facing walls, nor in the direction of strong, cold, winter winds.

The U-value of external doors in passive houses must be equal to, or less than 0.8W/m²C° (Kaufmann et al. 2004, p.22).

Passive House Characteristics

To reduce the energy consumption of a building (such as in a passive house), heating and cooling energy consumption must be reduced. Heating energy consumption in winter is reduced when heat loss is decreased and (external and internal) heat gains are increased. To reduce cooling energy consumption in summer, heat gains must be reduced and/or passive cooling methods (earth cooling, evaporative cooling, etc.) must be used. Passive houses are buildings which, with the use of the above mentioned strategies, particularly, by reducing heat loss require minimal energy consumption.

Although the greatest differences between passive houses and other buildings are in the construction details, they must also display variations in architectural characteristics, particular for climate responsive houses, such as, optimal orientation, compactness, etc.

Because south-facing windows receive more solar radiation in winter and less in summer and also provide the most suitable indoor heating conditions during summer and winter, passive houses must be orientated to the south. They must also be elongated in the east-west axis to maximise the area of south-facing walls.

Another important part of the passive house concept is the optimal shape of the house. The consequence of this is that only compact bodies should be used (Scandinavian Homes Ltd. 16.07.2008). Compactness is defined as the proportion of outside surface of a building to its volume. The more compact a building, the smaller the heat loss and cost for insulation material.

A passive house can also be built of masonry materials or light weight materials such as wood. Masonry materials can be used as thermal storage mass for storing the heat for later use. This is one of the major advantages of massive construction in comparison to timber construction. However, light weight buildings can be built in short time and with less money. Passive houses have some special characteristics that distinguish them from conventional buildings. The general characteristics of passive houses are stated in following table:

Table 24: General characteristics of passive houses, Source: Based on various references including Feist 2001, pp.5-40, Feist 2006a,b,c,d,e,f,g, Feist 2007a,b and Redman and Redman 07.09.2004, Kaufmann et al. 2004, p.22 (my compilations and editions)

Factor	Characteristic
Building shape	A Compact Building with minimal surface area
Orientation	Southern orientation
Building envelope	Well insulated opaque envelope, without thermal bridges
	Tight building envelope
Insulation	Huge Thermal Mass and thick insulation (250mm walls, 250mm floor, 400mm roof)
Apertures	Passive use of solar energy (High solar gains of the building through apertures)
	Large South facing windows, with small windows on the North side of house
	Little shaded apertures (shade considerations)
	Triple glazed windows
	Well insulated window frames
	As few external doors as possible
	All External doors open via Thermal Buffer Zone
Ventilation system	Passive preheating of fresh air with passing air through underground ducts that exchange heat with the soil
	Heat Recovery Systems
	Compact Devices for Ventilation, Warm water and Heating
	Whole house ventilation system with heat exchange
	Highly efficient heat recovery from exhaust air (using an air-to-air heat exchanger)
Household	Energy saving Household Appliances (low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc.)
	Use of solar collectors or heat pumps provide energy for hot water
Heating System	No conventional fossil fuel central heating

Passive House Standards

Passive houses have some characteristics, which define them as passive houses. These features are classed under different categories such as energy demand and building construction. Although the passive house standard differs depending on climate, the following characteristics are common for all passive houses in Europe where, up until now passive houses have been used. Standard rules for passive houses are stated in following table:

Table 25: Standard rules for passive houses, Source: Based on various references including Feist 2001, pp.6-42, Feist 03.12.2006a,b,c,e,f, Feist 2007a,b, Berndgen-Kaiser 2004, pp.11-23, Graf 2003, pp.11-20, Kaufmann et al. 2004, p.22 (my compilations and editions)

Main Factor		Factor	Standard
Energy	Heating energy requirement	Annual space-heating requirement	≤ 15kWh/m²a
		Heating power (constant heating-load)	≤ 10W/m²
		Heating power for one family house	≤1.600W
		Heating energy consumption for one family house	≤2.000Wh/a (200 l Oil)
	Energy requirement	Total energy requirement (for space-heating, domestic hot water and household appliances)	≤ 120kWh/m²a
Window	U-factor	U-factor of glazing	0.6 ≤ Ug ≤ 0.8W/m²K
		U-factor of window frame	0.5 ≤ Uf ≤ 0.9W/m²K
		U-factor of windows (glazing and frames, combined)	Uw ≤ 0.80W/m²K
	Solar coefficient	Solar heat-gain coefficient of windows	50% ≤ g
Door	U-factor	U-factor of external doors	Ud ≤ 0.8W/ m²C°
Opaque thermal envelope	Insulation	U-factor of all opaque components of the thermal envelope	U ≤0.15W/m²K
		The thickness of insulation material	25 - 40cm
		Thermal bridge heat loss coefficient	≤ 0.01W/mK
	Air change	Air change rate at 50 Pa	n_{50} ≤ 0,6 /h
Ventilation system	Grade	Heat recovery grade (efficiency) of ventilation system	75% ≤
	Electricity consumption	Electricity consumption of ventilation system	≤ 0.4W/m³

Energy Supply of Passive Houses

Due to the minimal heat loss in passive houses, and the use of heat exchangers for heat recovery, the passive houses need little energy. These houses receive their energy supply from internal and external heat gains and a little from fuel. A passive house gains its heating energy from the following sources:

- Solar heat gain through transparent elements

- Heat emission through house appliances such as lighting, cooker, etc
- Body heat from occupants
- Ground heat (with the use of an earth heat exchanger)
- Fuel heating of supply air

"The heat inputs are delivered externally by solar radiation through the windows and internally by the heat emissions of appliances and occupants. These inputs are essentially sufficient to keep the building at a comfortable indoor temperature throughout the heating period. The minimal heat requirement can be supplied by heating the supply air in the ventilation system – a system, which is necessary in all housing" (HANDS ON 16.07.2008).

Use of Passive Solar Heating System in Passive Houses

Passive houses use solar heating to supply some of the winter heating energy requirements via the windows. If passive solar heating systems are used in these types of buildings, their heating energy consumption will be reduced. Passive houses have some south-facing windows, but other parts of their south-facing walls, roof and even the courtyard and its walls, also receive sunrays in winter, when the house needs heating energy. Therefore, if we can passively use this energy for heating the building (or to heat domestic water, etc.), the heat load and thus the energy consumption of a building will be reduced. If we use passive heating systems in passive houses, in a cooling period, these systems must be out of operation to avoid overheating.

Use of Direct Gain in Passive Houses

A passive house gains a large amount of its energy need from solar heating via non-diffusing direct gain systems through windows. To increase the efficiency of direct heat gain in passive houses, this it must have the characteristics of a "passive solar direct gain system".

In a passive house, enough of the storage mass must be placed to absorb excess heat during the day and re-emit it at night, when it is needed. The sunlight must shine directly onto this thermal mass for it to be efficient. Other kinds of direct gain systems such as: diffusing direct gain, clerestory and skylight systems can be also used in passive houses.

Use of Indirect Gain in Passive Houses

Indirect gain systems consist of a trombe wall, water wall, remote storage wall, simple U-tube collector, thermosiphoning wall and storage roof system. Due to the use of high insulated elements (walls and roof) in passive houses, use of some indirect gain subsystems such as the trombe wall and storage roof systems in passive houses is not possible. This is because in these systems some absorbed heat will be transferred directly from the system into living spaces through the wall or roof via the conduction and this is not possible in passive houses because of the highly insulated elements. However, remote storage walls and U-tube collectors can be used in passive houses to gain solar heat.

Remote Storage Wall System

In remote storage wall systems, there is an external south-facing glazing surface and an insulated masonry or concrete wall behind it, which is insulated on the room side and has two vents at the top and bottom of the storage mass to allow air to circulate through to the heated space. In this system, the energy transmission through the wall via conduction and radiation is prevented by insulation; and all heat is transferred by convection, possibly fan-assisted.

Solar radiation falls through the window, onto the storage wall and is absorbed by it, causing the surface of the masonry to warm up and heat the air between the wall and window. Hot air rises and enters the living space via the upper vents, causing the cool air to be drawn from the room into the collector air space through the lower vents.

Depending on the climate and the system, this circulation continues some hours after sunset. After that, it changes into reverse. Such a reversal convects the heat from the living space to the collector air space. Therefore, to avoid losing the heat in the room, the vents can be controllable by dampers.

Use of Remote Storage Wall Systems in Passive Houses

If a glazing surface (single or double) is used on the south-facing wall of a passive house with some distance from it, or from the south-facing part of its double-pitched roof, it can play the role of a remote storage wall. This wall will be heated by sunrays causing the heated surface of the wall to heat the air between the wall and glass. This heat can be transferred to the living space by natural convection or can even enter the heat exchanger to reduce its energy consumption for heating the air entering the living rooms. In this case, the vents at the top and bottom of the wall must be airtight and have a U-factor of less than 0.15 W/m²K (like the wall) that prevents heat loss through these vents.

This wall has two layers more than the normal walls of a passive house. These layers are of air and glass. Therefore, in order to have the required U-factor (less than 0.15 W/m²K), the insulation material of the wall can be reduced in thickness. Accordingly, to add a layer of glass to the wall will not make it not cost-efficient.

Simple U-Tube Collector

A simple U-Tube collector is a convective loop, which provides additional heat during the day. In this system, there are south-facing, vertical or tilted glazing surfaces, an insulation layer behind (that together make a box) and a metallic absorber located between the window and insulation. The metallic absorber collects solar radiation, becomes warm and warms the air in the collector. The heated air flows into the heating space, and cooler air flows from the heated space into the collector. A natural circulation occurs between collector box and heated space.

Use of U-tube Collectors in Passive Houses

Because in passive houses the outside air continually enters the building through a ventilation system (heat exchanger), it is possible for the heated air from a passive solar system to enter the ventilation system. Thus, to reach the needed temperature, this air needs less energy. Therefore, it is possible to use U-tube collectors in passive houses. If a U-tube collector is added to the start of the pipe in which the outside air enters the ventilation system, the air will be heated by sunrays in this system, before it enters the heat exchanger, therefore minimising the energy consumption. If in the days of the heating period, this heat is not needed for space heating, it can be used for heating the domestic hot water.

Passive Houses in Summer

During summer, the high thermal insulation of the building envelope is a protection against heat. To ensure high thermal comfort during summer, well-designed shading and sufficient ventilation are important as well (Global Passive House Technologies Inc. 14.05.2008). Large amounts of thermal mass in the building will moderate the inside air temperature and natural ventilation with summer winds can also be useful.

The ground during the summer has a lower temperature than outdoor air. The air thus can be cooled in summer by circulating through the buried pipes of the ventilation system. Ground cooling with air uses the long-term thermal inertia of the ground[1] to extract “coldness” in the summer through air to ground heat exchangers. These heat exchangers are usually made of buried pipe networks through which outside or building air is blown, thus cooling it (Reisinger et al. 2002, p.21).

Energy Use of Household Appliances

The energy consumption of household appliances is out of the limits of the present research, for the architectural characteristics of passive houses is the main focus. However, in a passive house the household appliances must also have little energy consumption. Therefore, not only must energy-saving household appliances (such as low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc.) be used in passive houses, but also solar collectors can be used for some energy needs such as domestic hot water.

[1] - A few meters below the ground level, the temperature varies only a few degrees from the yearly mean temperature.

Chapter Four: Analysis

Introduction

Iran pays large amounts of subsidies on oil production, especially for energy used in building heating and cooling. Therefore, the energy price in Iran is very low (in comparison with international prices). For this reason, nobody pays attention to energy saving, especially when it would increase the building costs, because the payback time is very long and the general population prefers to build a cheap, high energy building, instead of an expensive, energy efficient building.

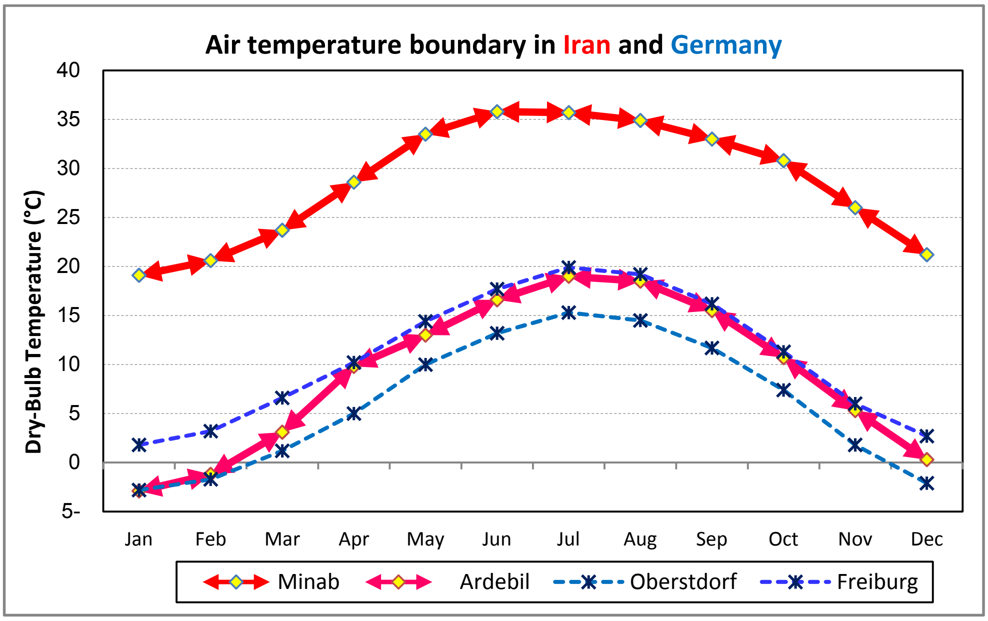
Because of the above reasons, people do not pay attention to the energy saving rules in buildings and do not also use active systems for energy saving and energy production. People are not interested in using insulation material, double or triple glazed windows with insulated frames, insulated doors, and other elements which would decrease the energy consumption of buildings, because the price of such materials is very high in comparison to energy. Energy saving rules, insulated materials, construction elements and also renewable energy systems are used only in some governmental projects and by private people only when it is compulsory. Therefore, in such a country with low energy prices and high construction prices, the use of cost-neutral or cheap energy saving methods, especially architectural methods is very important. Architectural methods do not often increase the building costs and are achievable only with suitable design.

This chapter tests the suitability of passive houses in the cold climate of Iran through a comparison of Germany and Iran using simulation and analysis of passive houses in this climate. Passive and architectural factors are found which reduce the energy consumption of buildings in this climate without increasing the building costs. These architectural factors can be used in the majority of houses in the cold climatic region of Iran to reduce their energy consumption, or can be used in passive houses effectively to reduce required insulation material and their costs. Then the energy efficient houses in Iran's conditions will be economically evaluated and a proper HVAC system for these buildings in the (climatic, technical and economical) conditions of Iran will be found.

Comparison of Iran and Germany

Climate

Iran and Germany have very different climates. In Iran there are dry and humid climatic regions but there are no such climates in Germany. The temperature difference between different cities in Iran is also very high because of diverse climatic regions but this variation is little in Germany. The following graph compares the average dry-bulb temperature of the coldest and warmest cities of Iran and Germany and shows the temperature boundary in these two countries in comparison with each other.



Source: Based on data from Iran Meteorological Organization 07.01.2008 and Klimadiagramme weltweit 01.01.2008a

Although a big part of the temperature boundary area in Iran is higher than the boundary area in Germany (i.e. Iran's cities are warmer than Germany's cities), these two areas have a common part. But (based on climatic data) all Iran's cold cities have less relative humidity and precipitation than Germany's (cold) cities.

Comparison of Climate of Tabriz and Munich

This section of present research is to compare and contrast the climates of Tabriz in Iran and Munich in Germany as case studies.

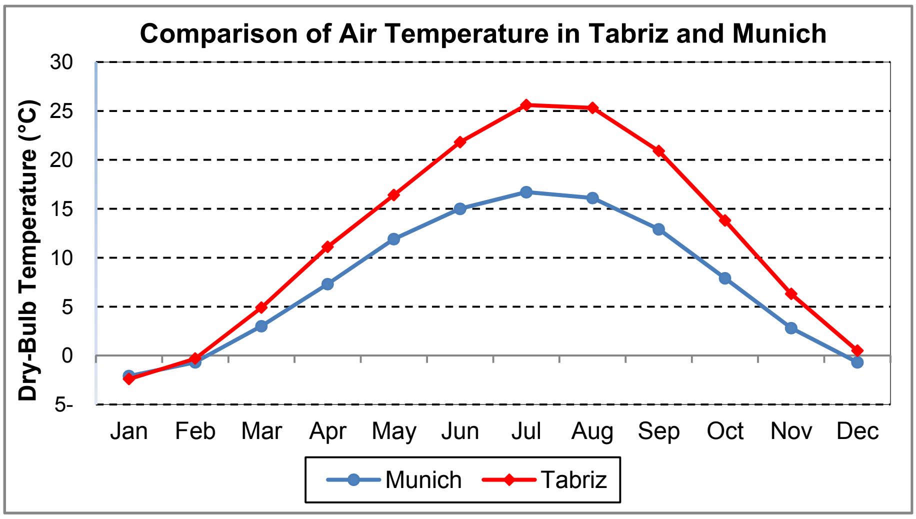
Based on the Köppen classification, Tabriz has a mid-latitude, dry, semiarid climate with unbearably hot, dry periods in summer (but passive cooling is possible). Munich has moist, continental, warm summers, and cold winter climates with no dry season. On the basis of ASHRAE standards Tabriz has a warm-marine, dry summer subtropical (Mediterranean) climate and Munich has a cool-humid, humid continental (warm summer) climate. The following table shows the general climatic information for Tabriz and Munich as the two case study cities of Iran and Germany.

Table 26: Climate information of Tabriz and Munich, Source: Based on data from U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

Factor		Tabriz	Munich
Latitude (°)		38.13	48.13
Longitude (°)		46.28	11.70
Elevation above sea level (m)		1361	520
WMO station identifier		407060	108660
Winter design weather data (99.6% Coverage)	Outside design temperature (°C)	-10.7	-11.9
	Wind speed (m/s)	10.5	10.3
Summer design weather data (99.6% Coverage)	Max dry-bulb temperature (°C)	35.1	29.4
	Coincident wet-bulb temperature (°C)	16.2	18.9
	Min dry-bulb temperature (°C)	23.1	20.6
Annual average dry-bulb temperature (°C)		12	7.5
Climate type	Köppen classification	BSk	Dfb
	ASHRAE Standards	3C	5A
Seasons	Summer	Jun:Aug	Jul:Sep
	Winter	Dec:Feb	Jan:Mar
	Autumn	Sep:Nov	Oct:Dec
	Spring	Mar:May	Apr:Jun
Extreme Summer Week	Extreme Hot Week Period	20:Jul 26	Jul 22:Jul 28
	Max Temp	37.10°C, Deviation=|9.069|°C	33.30°C, Deviation=|12.728|°C
Typical Summer Week	Typical Week Period	Jun 15:Jun 21	Jul 15:Jul 21
	Average Temp	24.41°C, Deviation=|0.391|°C	16.31°C, Deviation=|0.044|°C
Extreme Winter Week	Extreme Cold Week Period	Jan 13:Jan 19	Feb 12:Feb 18
	Min Temp	-13.40°C, Deviation=|7.457|°C	-16.50°C, Deviation=|7.038|°C
Typical Winter Week	Typical Week Period	Jan 27:Feb 2	Jan 8:Jan 14
	Average Temp	-1.29°C, Deviation=|0.555|°C	-0.04°C, Deviation=|0.259|°C
Typical Autumn Week	Typical Week Period	Sep 29:Oct 5	Oct 22:Oct 28
	Average Temp	13.55°C, Deviation=|0.136|°C	4.13°C, Deviation=|0.400|°C
Typical Spring Week	Typical Week Period	Apr 12:Apr 18	Apr 1:Apr 7
	Average Temp	10.80°C, Deviation=|0.122|°C	11.37°C, Deviation=|0.291|°C

Air Temperature

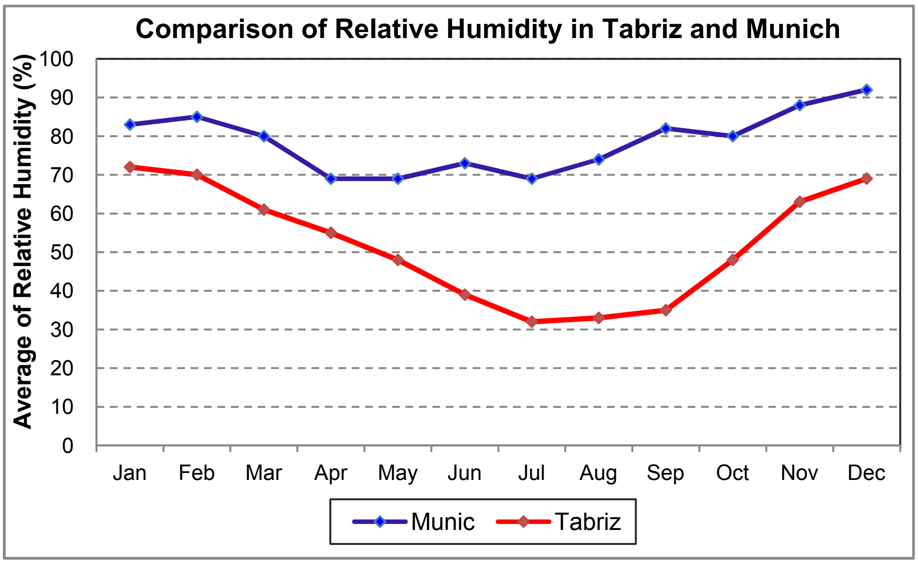
The following diagram compares the monthly average dry-bulb air temperatures of Tabriz and Munich. The air temperature of Tabriz is less than in Munich only for January. In the other winter months, and especially in summer months, it is more than Munich. The temperature difference between winter and summer in Tabriz is also significantly more than Munich.



Source: Based on data from Iran Meteorological Organization 07.01.2008 and Klimadiagramme weltweit 2008a

Relative Humidity

This graph compares the monthly average relative humidity of Tabriz and Munich. The relative humidity of Tabriz is in all months less than in Munich and also the difference in relative humidity in winter and summer in Tabriz is much more than Munich.



Source: Based on data from U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

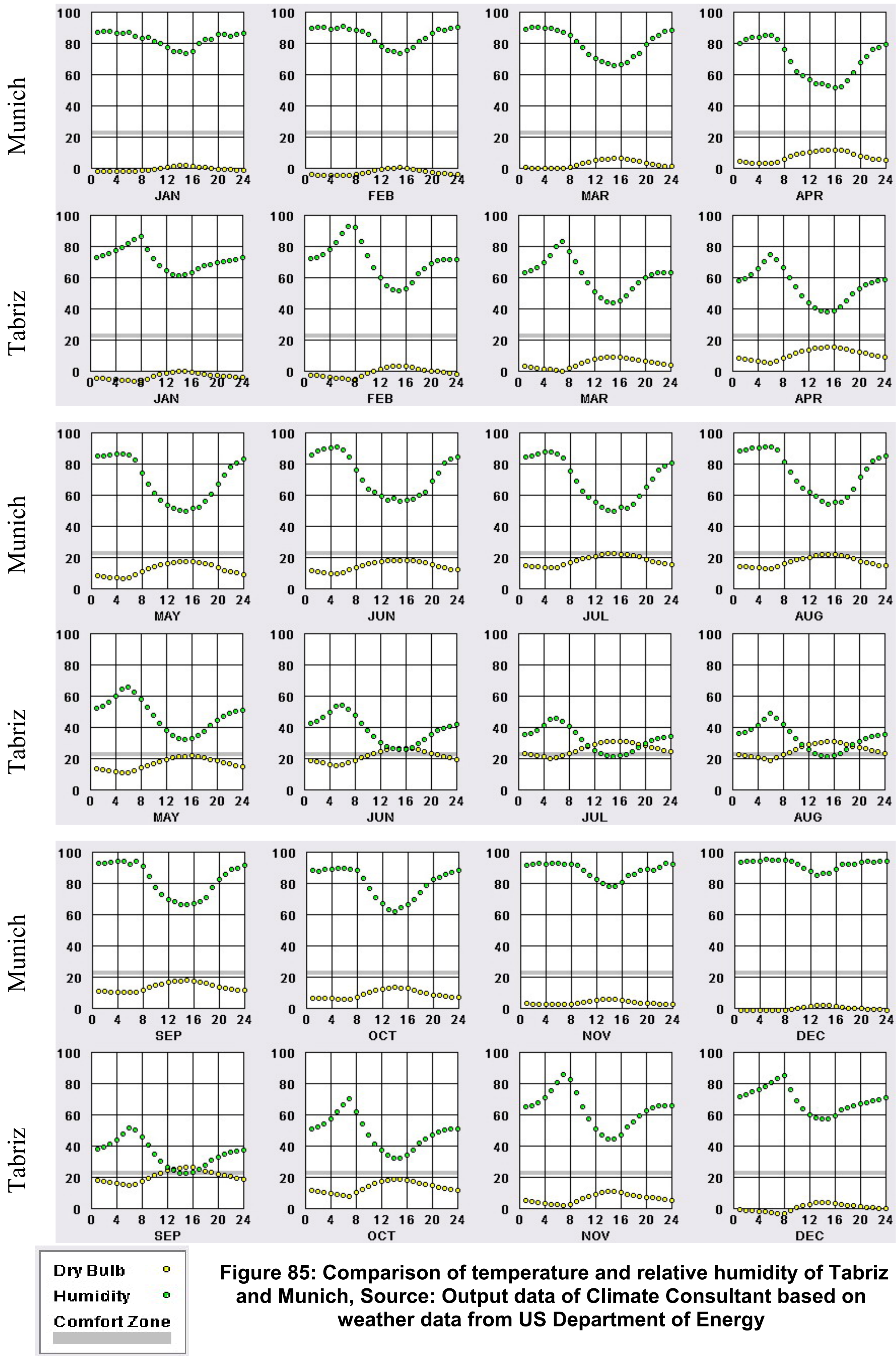


Figure 85: Comparison of temperature and relative humidity of Tabriz and Munich, Source: Output data of Climate Consultant based on weather data from US Department of Energy

The last table compares the dry bulb temperature and relative humidity of Tabriz and Munich in different months. It shows that the relative humidity of Munich in all months, especially during the cooling period, is much more than Tabriz and the air temperature of Tabriz in summer is more than Munich.

The following figure compares the temperature timetable of Tabriz and Munich. It shows that the air temperature of Tabriz, especially in summer, is much more than in Munich, and Tabriz therefore needs much more cooling energy.

Munich Tabriz

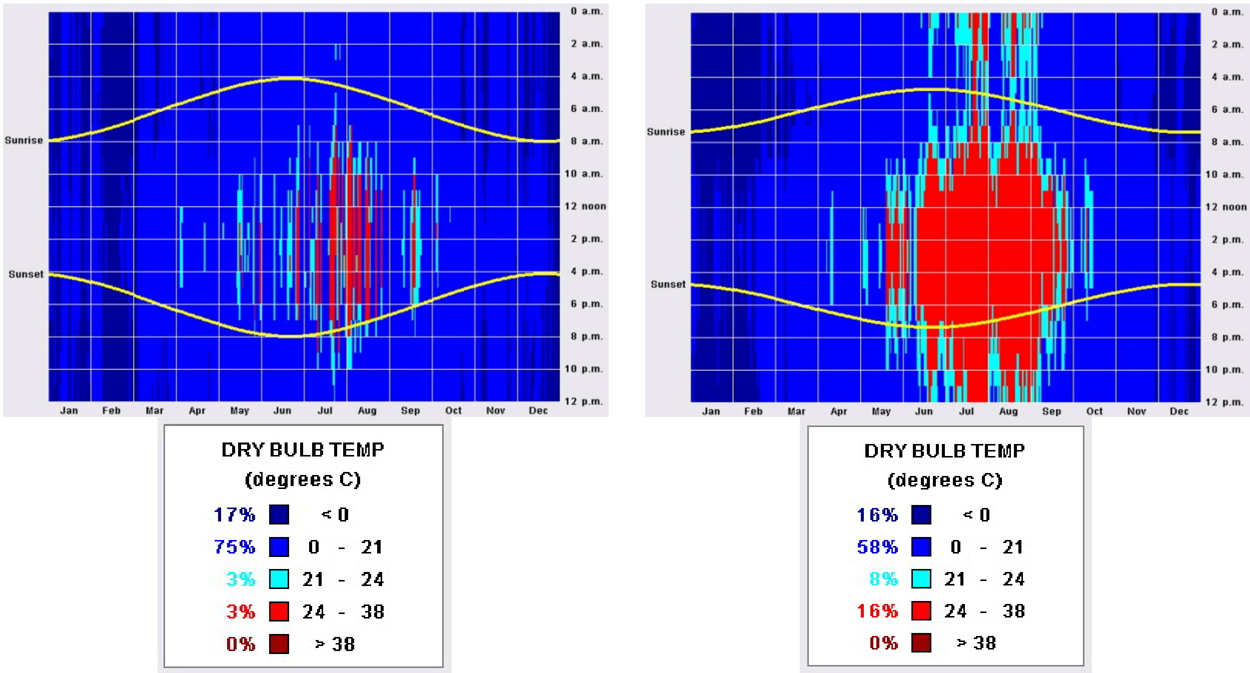
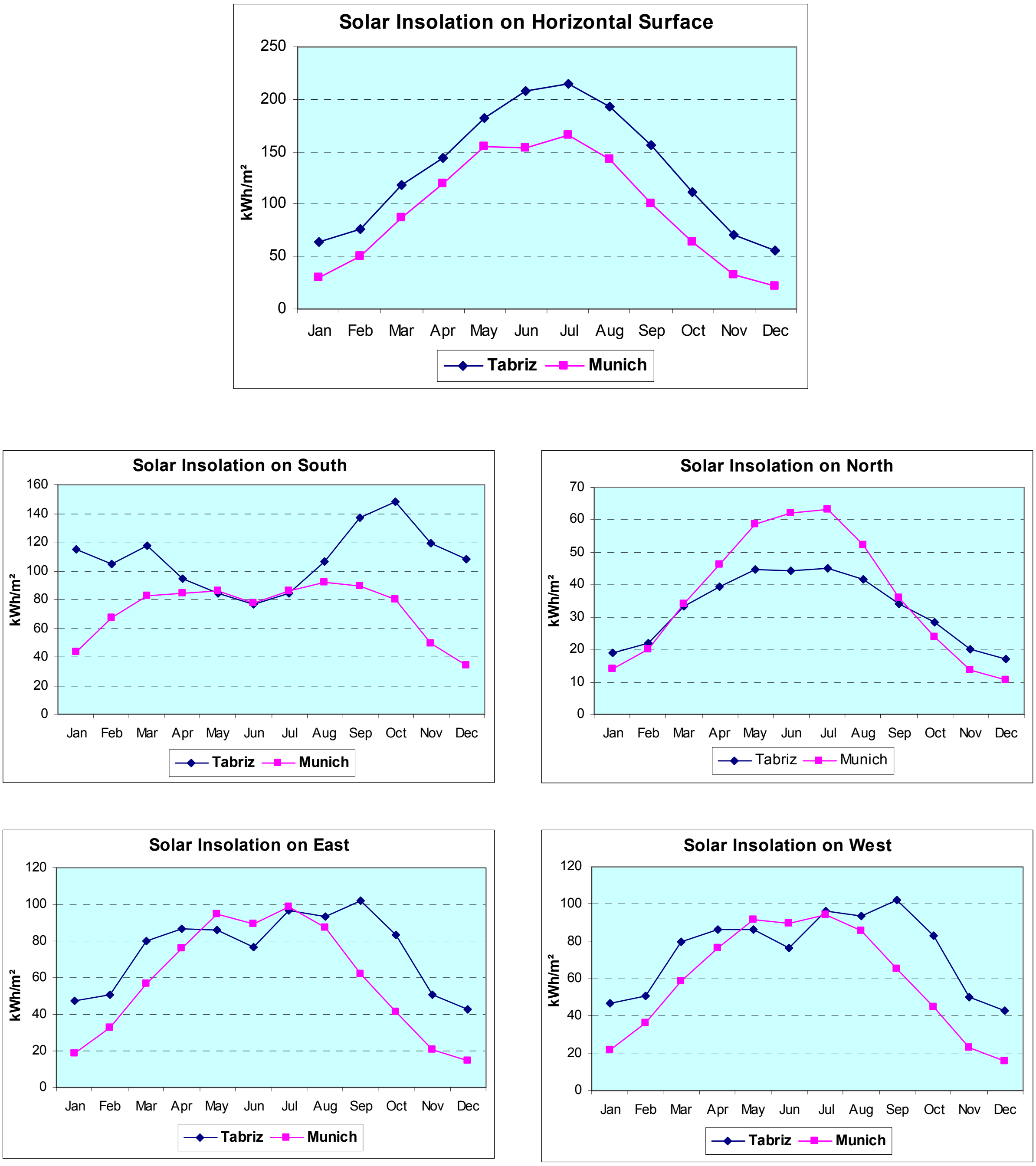


Figure 86: Comparison of temperature timetable of Tabriz and Munich, Source of Weather Data: U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

Solar Radiation

The following graphs compare the monthly average solar radiation in horizontal surfaces and other orientations in Tabriz and Munich. From these diagrams is can be seen that the global solar insolation of Tabriz, for horizontal surfaces, is more than Munich. Although the solar radiation received by other orientations during the summer months in Tabriz is less than Munich, these orientations receive much more solar radiation (in Tabriz) in winter, when it is needed. Therefore, the amount of solar radiation in Tabriz corresponds better to the requirements in both winter and summer.



Comparison of solar radiation in Tabriz and Munich, Source: Based on data from NASA 27.07.2006

Wind

The following graphs, representing the wind wheels of Tabriz and Munich, show that there is a prevailing wind in Munich which blows from southwest to northeast. But in Tabriz there is no such a prevailing wind. The relative humidity of winds in Munich is also more than in Tabriz.

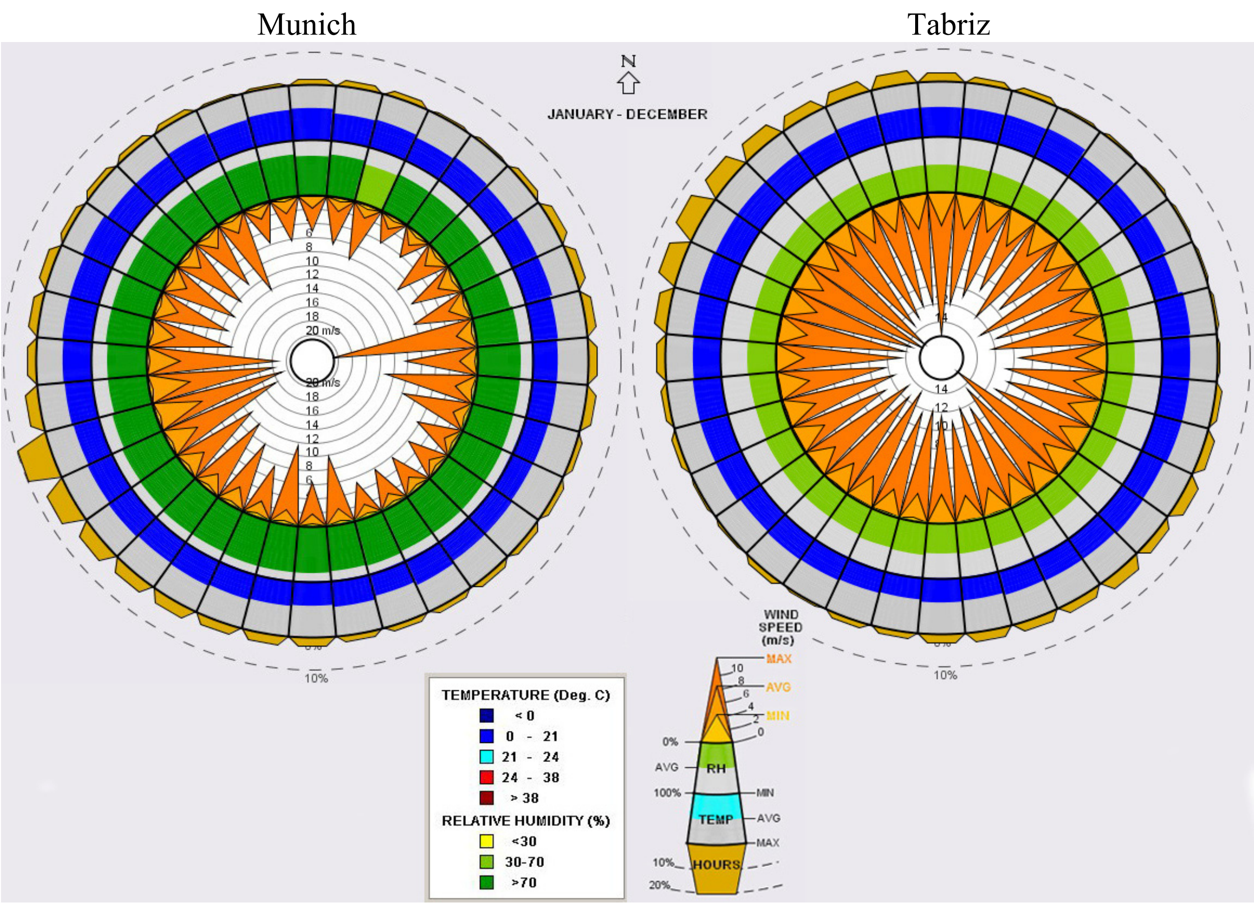


Figure 87: Comparison of wind wheel of Tabriz and Munich, Source of Weather Data: U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

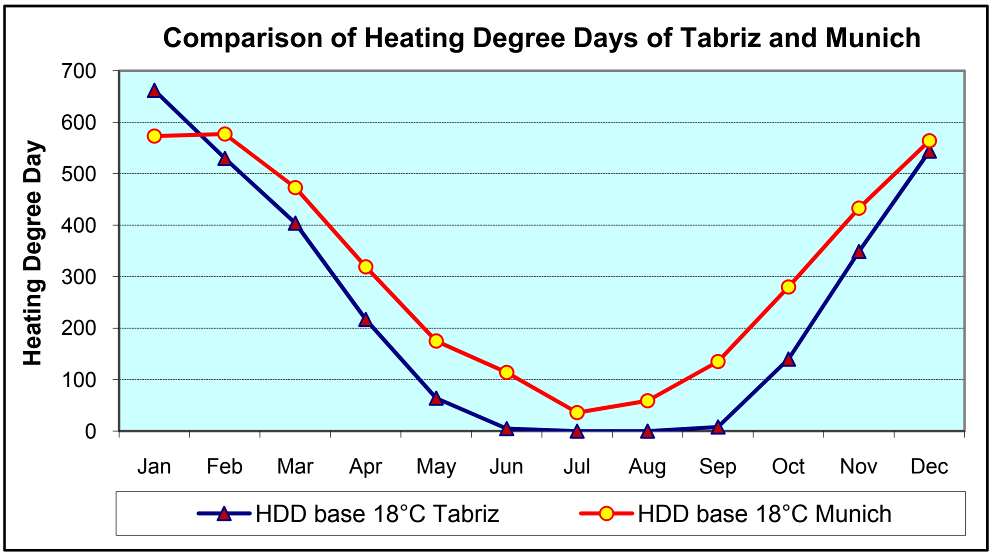
Heating and Cooling Degree Days

Heating and cooling degree days present the amount of heating and cooling required for every climate and thus they are suitable factors for climatically comparing the two cities. The following table presents the heating and cooling degree days of Tabriz and Munich, based on 18°C, and for more detail the cooling degree hours of these two cities, based on 27°C.

Table 27: Heating and cooling degree days and cooling degree hours of Tabriz and Munich, Source: Based on data from U.S. Department of Energy 14.01.2008b and 08.08.2008c

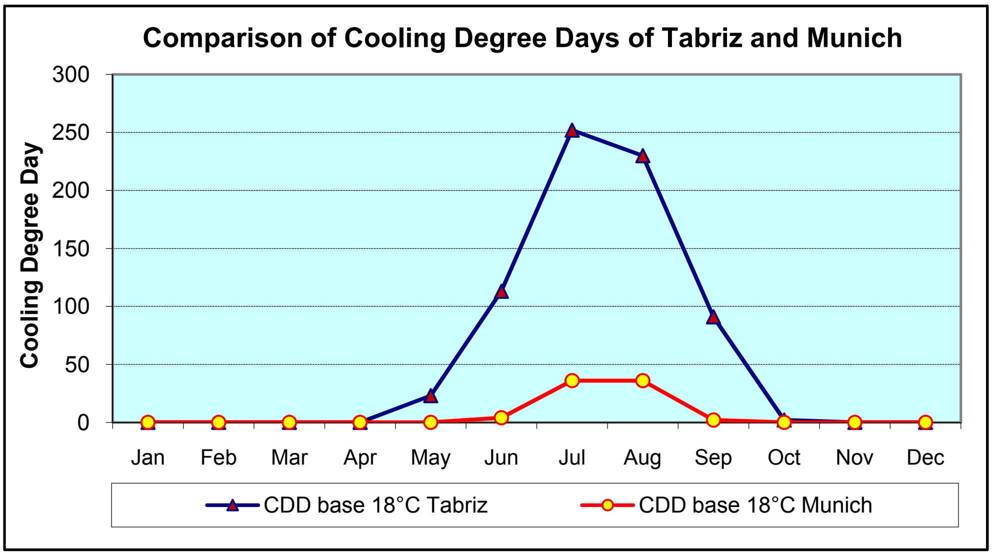
	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
HDD base 18°C	Tabriz	662	530	404	217	64	5	0	0	8	140	349	544	2923
	Munich	573	577	473	319	175	114	36	59	135	280	433	564	3738
CDD base 18°C	Tabriz	0	0	0	0	23	113	252	230	91	2	0	0	711
	Munich	0	0	0	0	0	4	36	36	2	0	0	0	78
CDH base 27°C	Tabriz	0	0	0	0	4	228	1083	859	97	0	0	0	2271
	Munich	0	0	0	0	0	0	101	64	1	0	0	0	166

The following graph compares the heating degree days (HDD) of Tabriz and Munich, based on 18°C. It shows that the heating degree days of Munich in all months (except January) is slightly more than Tabriz, and shows also that Munich is in all months (except January) slightly colder than Tabriz. Based on this graph, the heating degree days of Tabriz in June, July, August and September are zero.



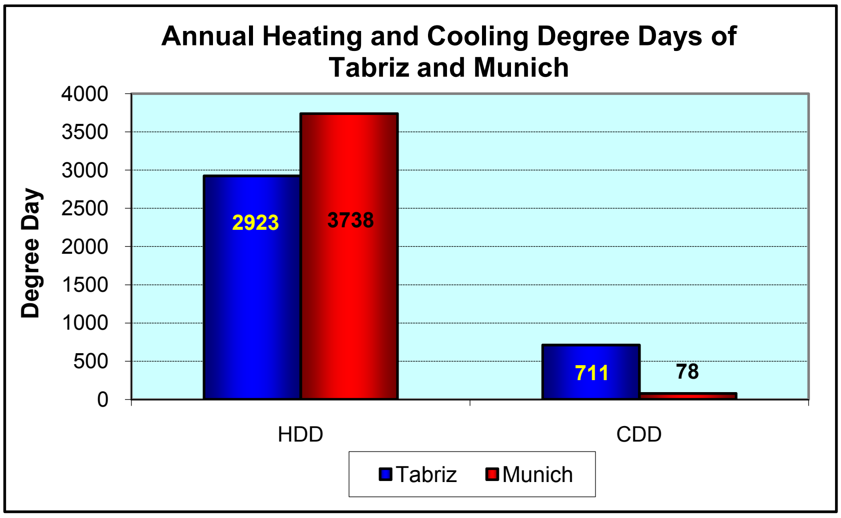
Source: Based on data from U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

This graph compares the cooling degree days (CDD) of Tabriz and Munich based on 18°C. It shows that the cooling degree days of Tabriz are more than Munich and shows also that Tabriz is warmer than Munich in summer. The cooling degree days of Munich, excluding July and August, is zero but Tabriz has a warmer summer and therefore needs cooling.



Source: Based on data from U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

The following graph compares the annual heating and cooling degree days of Tabriz and Munich and shows that Tabriz has less heating and more cooling degree days in comparison with Munich. Therefore, Tabriz needs less heating energy and more cooling energy in comparison to Munich.



Source: Based on data from U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

The following graphs show the daily amount of air temperature, wind speed, wind direction, air pressure, and the direct and diffuse solar radiation in Tabriz and Munich.

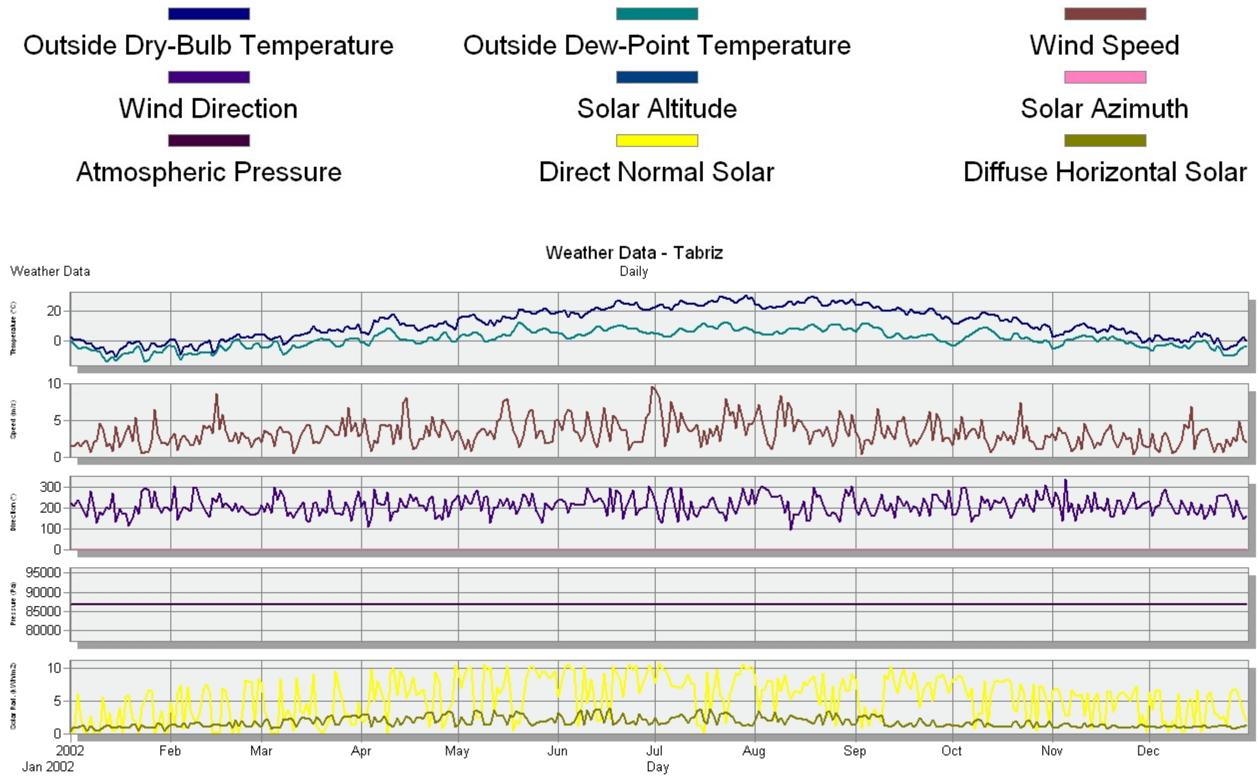


Figure 88: Daily climatic factors in Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

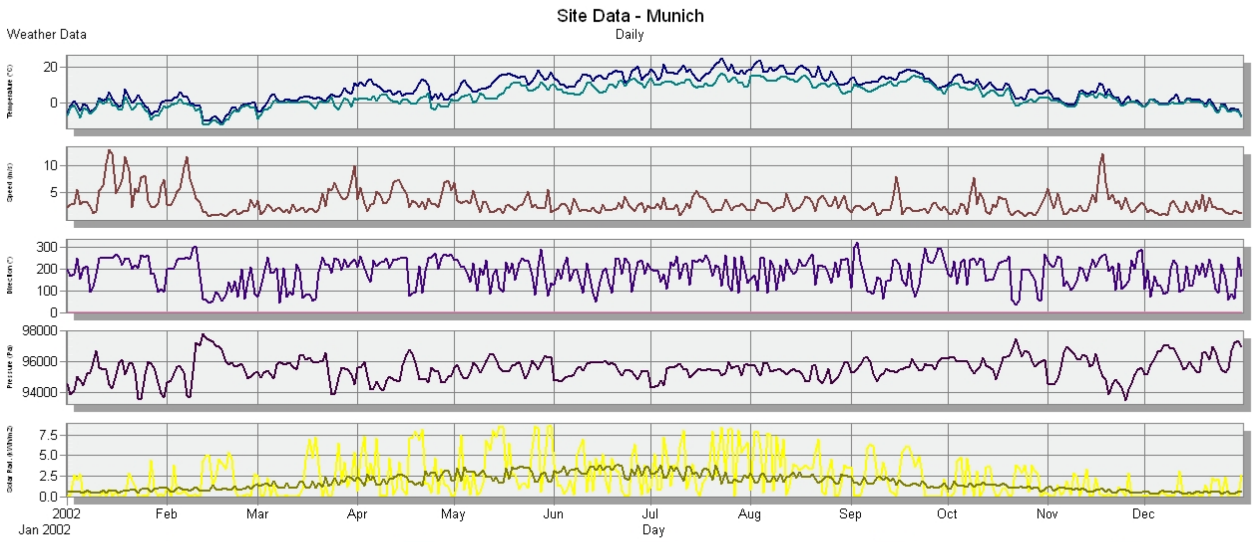


Figure 89: Daily climatic factors in Munich, Source of Weather Data: U.S. Department of Energy 08.08.2008c

Comparison of these two graphs shows that:

- Tabriz has a warmer summer than Munich.
- The difference between dry-bulb and wet-bulb temperatures in Tabriz is significantly more than in Munich, whereas relative humidity in Tabriz is less than in Munich. Therefore, evaporative cooling in Tabriz is also more effective than in Munich.
- Tabriz has much more solar radiation (especially direct solar radiation) than Munich during the year. Tabriz also has much more solar radiation in winter compared to Munich

Psychrometric Chart Comparison

The following graphs show the Psychrometric charts of Tabriz and Munich based on dry-bulb temperature.

Munich Tabriz

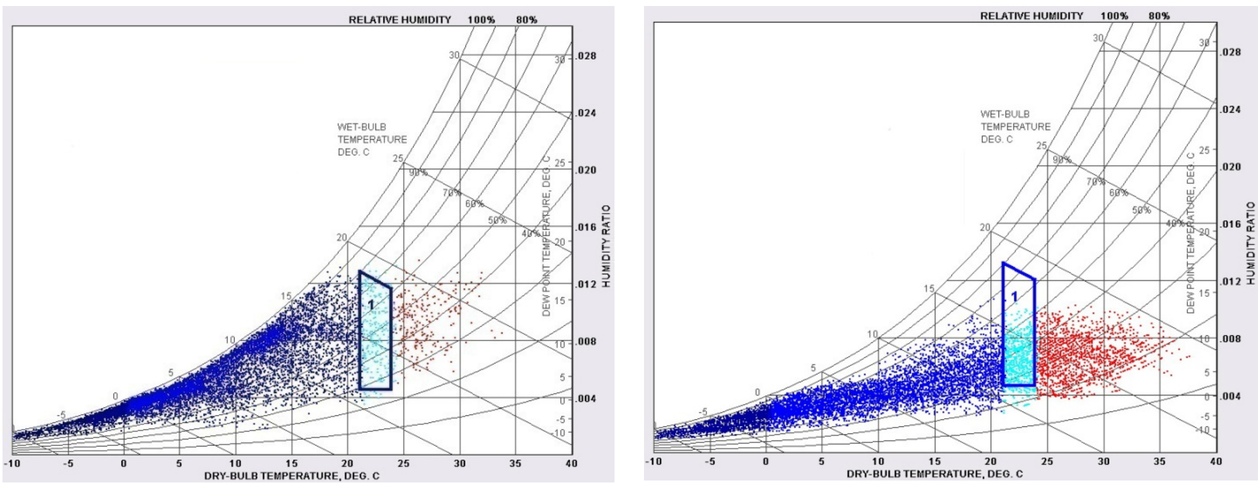


Figure 90: Comparison of psychrometric chart of Tabriz and Munich, Source of Weather Data: U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

Based on the psychrometric charts of these two cities, the time percentage of different temperatures in these two cities is as following:

Table 28: Comparison of temperature ranges in Tabriz and Munich with their annual time percentages, Source of Weather Data: U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

Temperature	< 0°C	0 - 21°C	21 - 24°C.	24 - 38°C
Tabriz	16%	58%	8%	16%
Munich	17%	75%	3%	3%

This table compares the time percentage of passive design strategies, conventional heating, and air conditioning needed in Tabriz and Munich.

Table 29: Annual time percentages of the application of various design strategies in Tabriz and Munich, Source of Weather Data: U.S. Department of Energy 14.01.2008b and U.S. Department of Energy 08.08.2008c

Strategy	Tabriz (%)	Munich (%)
Comfort	7.2	2.8
Sun shading	14.9	5.1
High thermal mass	11.0	3.1
High thermal mass/ night flushing	0.3	0.1
Direct evaporative cooling	16.8	2.2
Natural ventilation cooling	4.7	1.6
Internal heat gain	15.8	13.8
Passive solar direct gain (low mass)	14.3	8.8
Passive solar direct gain (high mass)	10.7	4.3
Humidification	53.7	43.3
Wind protection	7.7	14.0
Conventional air conditioning	0.5	0.0
Conventional heating	47.6	75.0

Climate Comparison Results

Heating (Winter)

- Tabriz has much more solar radiation in winter compared with Munich and other cities of Germany. This solar radiation can be effectively used for heating the passive houses in Iran. Therefore, passive use of solar heating through windows with suitable orientations and window ratio is very relevant in passive houses of Tabriz.

- Tabriz has less heating degree days and more solar radiation in winter than German cities. Therefore, passive houses in Iran are more easily achievable and require less thermal insulation.

Cooling (Summer)

Iranian cities (including Tabriz) are warmer than the German cities in summer. Therefore, passive houses in Iran and Germany must be different. The passive houses of Germany can not be applied directly to Iran because overheating would occur in these houses in summer.

- The houses of Iran, especially those that use more solar heat (such as passive houses) need cooling. Therefore, reducing cooling energy for passive houses with passive methods is very important.

- Tabriz has higher solar radiation (especially direct solar radiation) in summer compared to Munich and other cities of Germany. This solar radiation can be controlled by shading devices. Consequently, shading devices are very effective for cooling the passive houses of Iran in summer. Therefore, different kinds of shading devices, their efficiency, and their system of operation must be studied and simulated for passive houses in Iran.

- The air humidity in Tabriz and other cities in the cold climatic region of Iran is less than in Germany and thus the difference between dry-bulb and wet-bulb temperature in Iran is higher than in Germany. The dry-bulb and wet-bulb temperature difference on the 21 July in Tabriz is 19.61°C while it is 9.95°C in Munich. Therefore, evaporative cooling in Iran is very effective and it is possible to use natural evaporation and vegetation cooling to cool the passive houses.

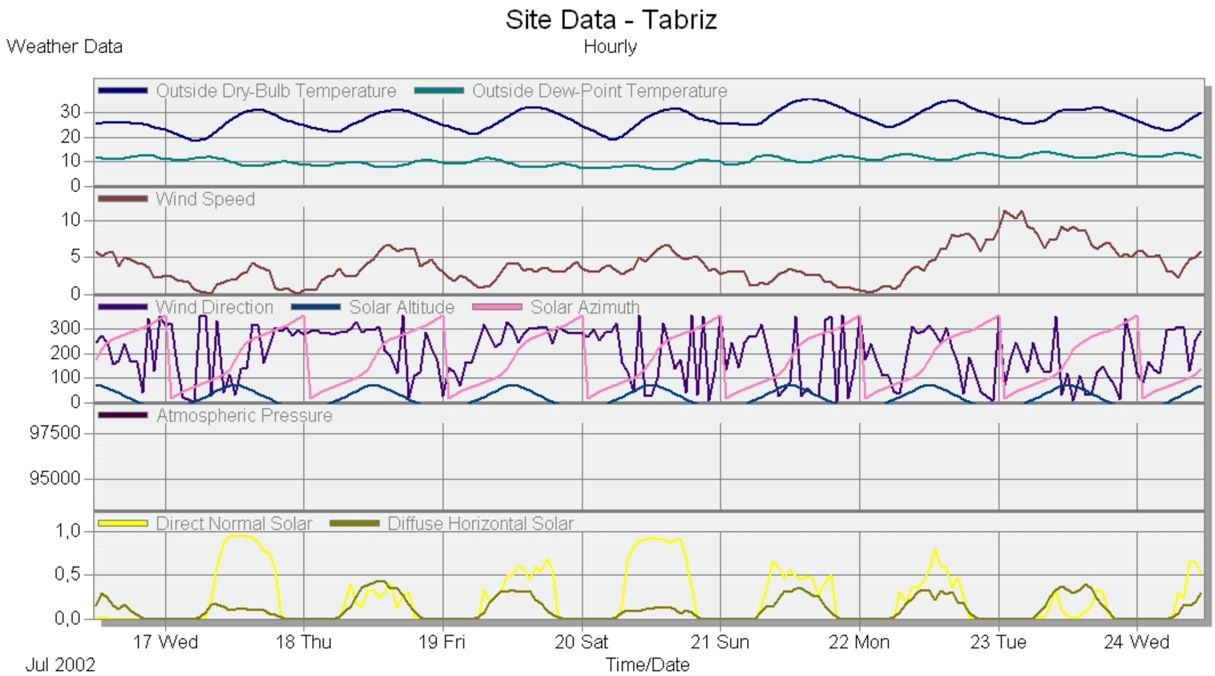


Figure 91: Daily climatic factors of one summer week in Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

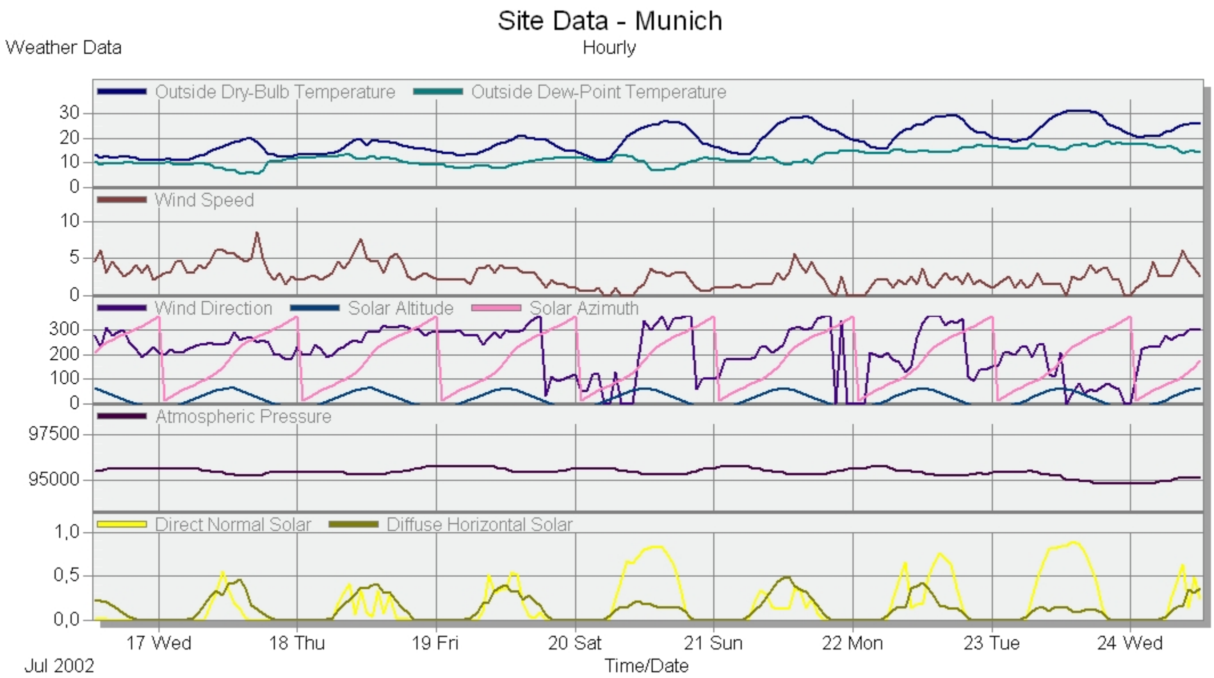


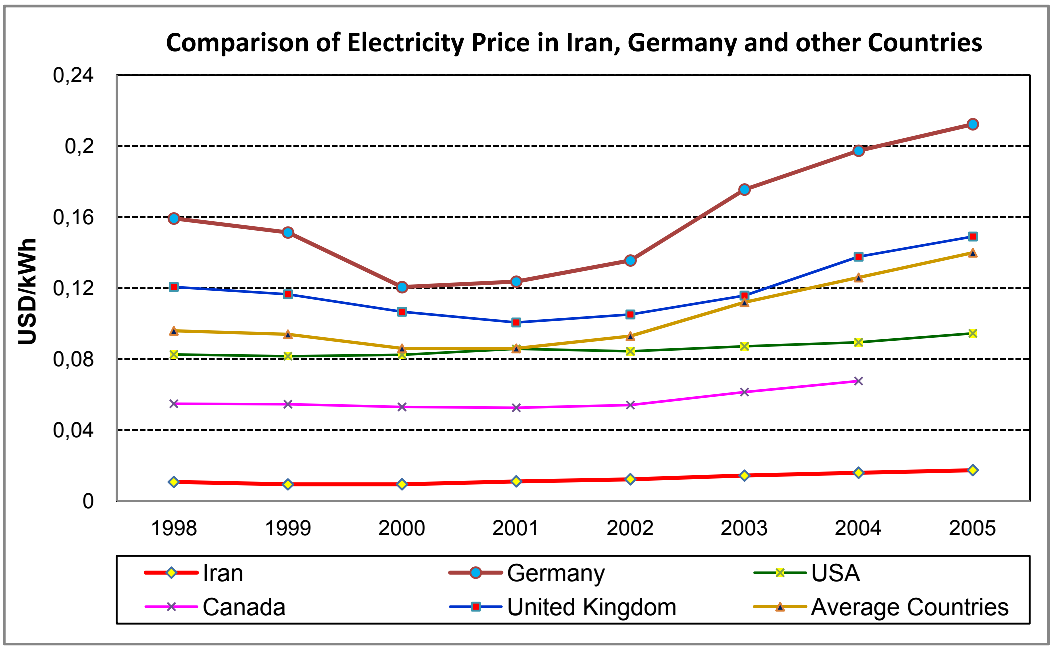
Figure 92: Daily climatic factors of one summer week in Munich, Source of Weather Data: U.S. Department of Energy 08.08.2008c

Energy

Iran is a country which exports energy, while Germany imports a big part of its required energy. The energy carriers used in Iran and Germany are also different. About 97%[1] (International Energy Annual (IEA), 2007) of the primary energy consumption of Iran belongs to petroleum products and natural gas, whereas in Germany only 58.7%[2] (tagesschau.de 2007b 09.01.2007b) belongs to these two energy carriers and the remaining to coal, nuclear power and renewable energy. Renewable energies are used more extensively in Germany than in Iran. About 4.6%[3] (tagesschau.de 2007b 09.01.2007b) of Germany's energy consumption belongs to renewable energies while the amount of renewable energies in Iran is 0.0038%[4] (Iran's Ministry of Energy, Energy Planning Department, 2006).

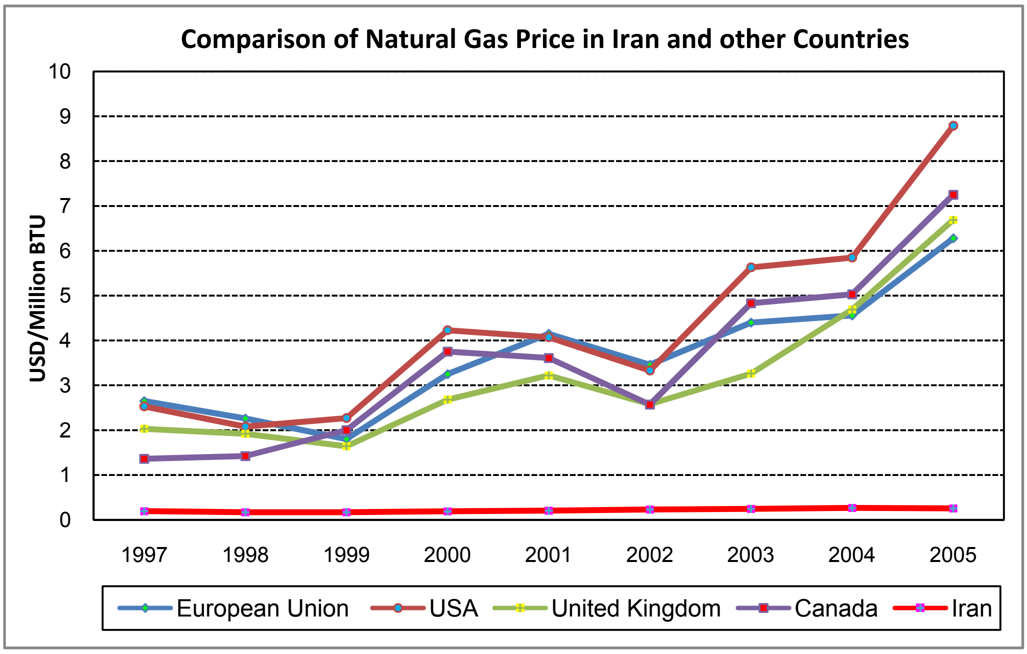
The energy price in Iran is much lower than in Germany and other countries. The following graph compares the price of electricity in Iran, Germany, USA, Canada, United Kingdom and the average in some other countries. It shows that the price of electricity in Iran is much less than Germany and other countries.

1 - Year 2004.
2 - Year 2005.
3 - Year 2004.
4 - Year 2004-05.



Source: Based on data from Iran Ministry of Energy 2006a, p.11, Table 1-1, Iran Ministry of Energy 2006a, p.495, Table 9-51 and Energy Information Administration 07.06.2007 (my calculations)

The following graph compares the natural gas price in Iran, European Union, USA, Canada and the United Kingdom. It shows that the price of natural gas in Iran is significantly less than other countries and is not dependent on the natural gas price fluctuations of other countries.



Source: Based on data from Iran Ministry of Energy 2006a, p.11, Table 1-1, Iran Ministry of Energy 2006a, p.456, Table 9-27 and Energy Information Administration 07.06.2007 (my calculations)

One of the main reasons for high energy consumption in all sectors and especially in buildings is the low energy price.

Building

Indoor Air Temperature (Comfort Zone)

Iran and Germany use different regulations for heating and cooling and these regulations have different temperature borders for comfort zones. Therefore, different heating and cooling set-point temperatures are used. Iran uses ASHRAE standards for HVAC systems but for internal heating and cooling design temperatures, and thus for comfort condition regulation, Iran uses the book "Building HVAC (Installation) Calculation"[1], in which the internal heating design temperatures are between 23.3 and 25°C (Tabatabaii 2002, p.48). Based on these design temperatures the heating set-point temperature is between 21.1 (with humidification) and 21.7 to 22.8°C (without humidification). Because most Iranian houses have big windows or uninsulated thermal envelopes, the maximum internal heating design temperature is used for mechanical heating equipment design and regulation[2]. Germany uses different standards for comfort conditions such as EnEV, DIN and ISO, and the comfort zone begins at 20°C (19°C, on the basis of some other standards). Therefore, this temperature is the heating set-point temperature in Germany.

Local clothing habits and thus preferred ambient temperatures vary between countries and cultures. Significant differences in clothing habits depend on the outdoor climate, among other things (Nicol and Humphreys 1972). Iranians normally wear light clothing at home and keep the indoor air temperature at the warmer temperature border of the comfort zone.

The temperature borders of comfort zones are affected by humidity (ASHRAE 2001, pp.812-24). Due to its low humidity, the preferred ambient temperature for the cold climatic region of Iran is higher. The thermal envelope of buildings in Iran also has a generally low thermal resistance; therefore, the indoor surface temperature and radiant temperature are low. The indoor air temperature must be higher in order to have a preferred ambient operative temperature and to create a comfortable indoor climate.

Based on the reasons mentioned above, the preferred winter indoor air temperature is higher in Iran than in Germany as well as the cooler temperature border of comfort zone. Therefore, the indoor and outdoor temperature difference, heat loss, and thus the energy consumption of buildings in Iran are more than in Germany.

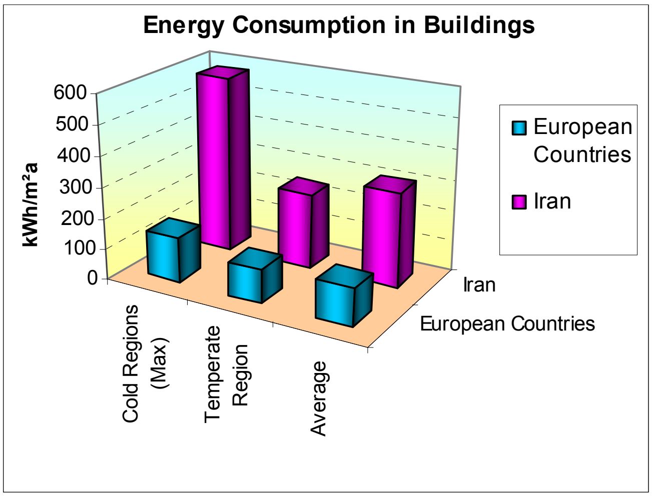
The internal cooling design temperature used in Iran is between 23.3 and 26.1°C (Tabatabaii 2002, p.48). Based on these design temperatures, the cooling set-point temperature is between 25 and 27.8°C.

[1] - This book is written by Mojtaba Tabatabaii and is based on standards of "Handbook of Air conditioning System Design", By: Carrier Air Conditioning Company and "ASHRAE Handbook of Fundamental".

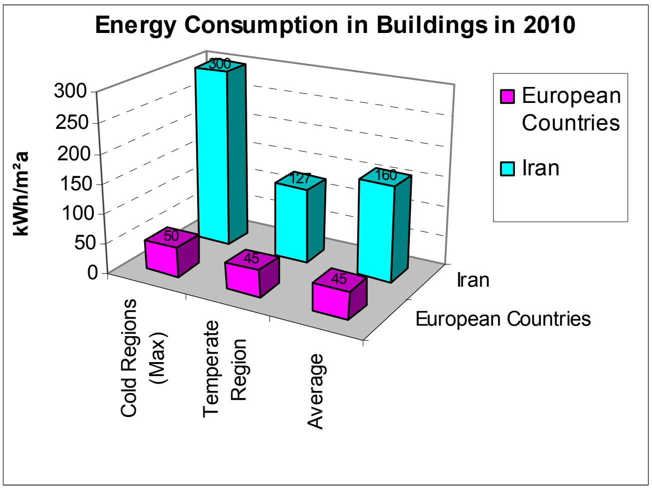
[2] - Based on (the regulation of) this book for mechanical heating equipment design of buildings with big windows or uninsulated walls, the higher range of internal heating design temperature must be used.

Energy Consumption of Buildings

Iran has higher energy consumption in comparison to other countries, in particular European countries. The energy consumption of buildings is very high, especially in Iran's cold regions (which constitutes a large area). The following graphs compare the energy consumption of Iran and European countries in 2005, and the planned energy conservation by 2010.



Comparison of Energy Consumption of Buildings in Iran and European Countries, Source: Based on data from Iranian fuel conservation organization 2005, p.1



Comparison of Planned Energy Consumption of Buildings in Iran and European Countries in year 2010, Source: Based on data from Iranian fuel conservation organization 2005, p.1

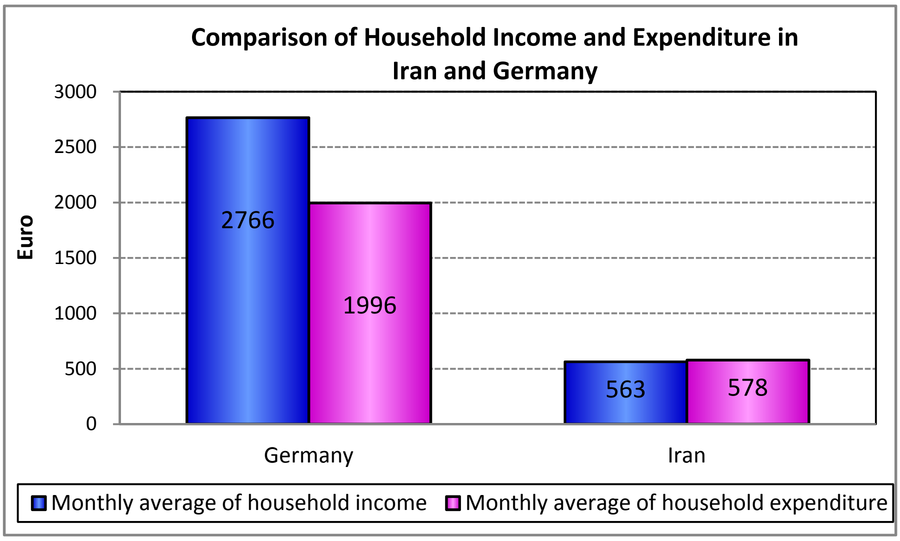
Building HVAC System

Due to the warm summers in Tabriz, the passive houses need both heating and cooling systems. Heat pumps can be used for both heating and cooling and are appropriate for passive houses in Iran. Because of Iran's high electricity prices in comparison with natural gas, the use of electricity heat pumps (which are used as heating systems in German passive houses) is not suitable in Iran. Therefore, heat pumps that consume natural gas are more appropriate as HVAC systems for passive houses in Iran.

Due to large differences between dry-bulb and wet-bulb temperature in Tabriz (and in other cities of the cold climatic region of Iran), an evaporation cooler can also be used as a cooling system in passive houses. Therefore, Heater-Cooler systems can also be used as HVAC systems in passive houses of Iran. This will be discussed further in the chapter titled 'climate data analysis'.

Economy

The average household income and expenditure in Iran is less than in Germany. The monthly average household income in Iran in 2005 was 550.32 Euros (6463000 Rial)[1] and the budgetary expenditure is 565.48 Euros (6641000 Rial) (Central Bank of Iran 2007b, pp.8-9) while the monthly average household income was 2766 Euros and the budgetary expenditure was 1996 Euros in Germany in 2005 (Statistisches Bundesamt 2007, D12.5V-D12.7V). It shows that the economic situation of Iranian families is much lower than in Germany. The following graph compares monthly average of household income and expenditure in Iran and Germany[2].



Source: Based on data from Central Bank of Iran 2007b, pp.8-9 and Statistisches Bundesamt 2007, D12.5V-D12.7V

Because of the low average income of middle class families in Iran, and the high price of using some building and HVAC technologies, it is economically unviable for most middle class Iranian families to use this technology. Therefore, the technology used in passive houses of Iran should be different from that applied in German passive houses.

Energy price in Iran is much less than in Germany and the building costs are more (relative to average income in these two countries). Thus, the use of expensive construction materials such as insulation material and double and triple glazed windows is not economically viable in Iran. Therefore, it is recommended that energy efficient architecture is used for passive houses of Iran to reduce the insulation material needed and building costs.

[1] - In year 2005, 1Euro was 11164 Rial (Central Bank of the Islamic Republic of Iran, 15.05.2008).
[2] - The data of Iran is from the year 2005-06 and the data of Germany is from 2005.

Building Energy Simulation in Iran

Building Energy Software Tools

Building energy software tools are very accurate and effective tools for evaluating building energy consumption and energy efficiency, for analysing the climatic data and building and system components, for evaluating the economy of energy saving, for performing whole-building energy simulation, etc.

Because building energy software tools give detailed and accurate analysis and time saving results, every part of analysis in present research uses a suitable software tool. Different energy software tools have different purposes such as evaluation, simulation and analysis. Therefore, the program selected must have the required characteristics and capabilities to provide quality results.

Climate and occupancy change daily and seasonally, and because they both interact with the building form, heating and cooling requirements are difficult to predict (Brown and Dekay 2001, p.53). Therefore, to analyse and understand the complex behaviour of a building's energy use, building energy simulation can be used.

Building energy simulation is the science of estimating the energy interactions within a building. These interactions include the direct purchase of energy, such as electricity for lighting or natural gas for heating, but also the exchange of energy due to such things as the infiltration of air into a building or the heat generated by a building's occupants. Simulation attempts to account for these factors, plus many more, in determining the heating, cooling and ventilation loads within a building, the equipment types and sizes needed to meet these loads, and the cost to operate this equipment plus other non-HVAC equipment (Caneta Research Inc. 08.05.2008).

One of the main sets of building energy software tools is simulation software tools, which are primarily used to calculate and determine the energy consumption of buildings during a given period and also to estimate the peak design thermal loads of the HVAC systems. Building energy simulation tools are the computer programs used for the energy calculations. They are effective analytical tools for the study of energy efficiency in buildings and thus energy simulation is important for building energy research.

"Simulation can help reduce energy consumption by modelling various strategies before they are built thus minimizing energy costs" (U.S. Department of Energy 2002-2003, p.2). Rapid promotion of computer simulation has meant that energy simulation using computer programs is widely used to detail and accurately appraise a building's energy performance.

"Building simulation software has developed very fast in recent years and new programs and versions are coming up frequently" (Hui and Cheung 1998, p.4). There are many different types of energy simulation software with different characteristics and capabilities. Some of the more developed building energy simulation programs are EnergyPlus, DesignBuilder, BLAST, DOE-2, Energy-10, TRANSYS, ESP-r, ASEAM, HAP, Ecotect, and PHPP.

One of the most popular and effective dynamic energy simulation programs is EnergyPlus, which models most of the architectural, constructional, environmental and mechanical features needed in energy efficient buildings. Therefore, this program is used for some simulation in this work. But because EnergyPlus reads and writes output as text files, one of its comprehensive graphical user interfaces (DesignBuilder) is more commonly used in order to graphically present the results.

Passive House Planning Package (PHPP) is also a stationary simulation program, which is used especially for simulating passive houses. This program is capable of simulating all building and system paraphernalia used in passive houses. Therefore, the present research uses it in the simulation of passive houses.

The three programs mentioned are used to determine the heating and cooling energy consumption of buildings with different architectural and constructional designs. In doing so, factors affecting the energy requirements of buildings and the characteristics of climate responsive buildings in the research area will be found.

There are also other building energy software tools that are used to analyse the climatic data, single components of buildings and systems, cost efficiency of energy saving, etc. From these programs, the present research uses “Climate Consultant” to display in graphics the climatic data for the cold climatic region of Iran and to analyse the psychrometric charts of the area to find the most appropriate passive design strategies for this climate. GAEA is used to calculate the energy saving rate and analyse the suitability of using earth heat exchangers in buildings. The “Economic Evaluation” Software is also used, to calculate the economic efficiency of investing in energy saving in buildings in Iran.

EnergyPlus

EnergyPlus is a building energy simulation program supported by the American Department of Energy which models: heating, cooling, lighting, ventilation and other energy flows, as well as water in buildings. While it is based on the most popular features and capabilities of BLAST and DOE-2, it includes many innovative simulation capabilities such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems. EnergyPlus is a stand-alone simulation program without a 'user friendly' graphical interface. It reads input and writes output as text files (U.S. Department of Energy 09.07.2008a).

EnergyPlus has several user interfaces that create and run EnergyPlus input files and display results graphically such as Demand Response Quick Assessment Tool, DesignBuilder, EFEN, Hevacomp, and HLCP. Some other software tools that have specifically been designed to create input files to simplify the use of EnergyPlus include: ECOTECT, EnergyPlugged, EP Geo, EP Sys, EP-Quick, IFCtoIDF, ESP-r, Green Building Studio, and IHIT.

Third-party tools for creating, editing, and displaying EnergyPlus input files include: DrawBDL, DrawEzPlus, EzPlus-Parm, TSe+Mat and TSE+Glz, and xEsoView (U.S. Department of Energy 09.07.2008a).

DesignBuilder

DesignBuilder is the first comprehensive user interface to the EnergyPlus dynamic thermal simulation engine. It combines rapid building modelling and ease of use with state of the art dynamic energy simulation. This program models natural ventilation, day lighting, and shading (louvres, overhangs, side fins, and blinds). Architectural features such as columns, awnings and complex shading devices can also be analysed including the effects of shading and reflection. DesignBuilder uses real hourly weather data and ASHRAE worldwide design weather data to calculate heating and cooling loads by using the ASHRAE-approved 'Heat Balance' method implemented in EnergyPlus. It analyses the effects of design alternatives on key design parameters such as: annual energy consumption, overheating hours, and CO2 emissions.

DesignBuilder shows the following simulation data in annual, monthly, daily, hourly or sub-hourly intervals:

- Energy consumption broken down by fuel and end-use.
- Internal air, mean radiant and operative temperatures and humidity
- Comfort output including underheating and overheating hours distribution curves, ASHRAE 55 comfort criteria (unmet loads), Fanger PMV, Pierce PMV ET, Pierce PMV SET, Pierce Discomfort Index (DISC), Pierce Thermal Sens. Index (TSENS), Kansas Uni TSV.
- Site weather data
- Heat transmission through building fabric including walls, roofs, infiltration, ventilation, etc.
- Heating and cooling loads.
- CO2 generation.

Compact HVAC systems of this program provide an easy way into detailed analysis of various commonly used heating and cooling systems including VAV with terminal reheat, constant volume, split air, fan coil units, heat recovery, packaged rooftop unitary DX, hot water radiator, underfloor heating, high temperature radiant heating, DHW, etc.

DesignBuilder can also generate rendered images with site shading; colour-coded layout images showing zone activities, cut-away sections and AVI movies of solar shading and scene orbit (DesignBuilder Software Ltd 10.05.2008).

Passive House Planning Package (PHPP)

The “Passive House Planning Package” (Passiv-Haus-ProjektierungsPaket) is a stationary monthly energy balance based on the former European standard EN832. The objective is to deliver the primary energy demand of a building. Therefore, the installed HVAC system is also considered. The main intention of the calculation is to prove the compliance with the German building standard “Passivhaus”. However, the PHPP is also a powerful tool for system design purposes in general. One of the Excel sheets in the file of PHPP is dedicated to compact units (Wemhöner et al. 2007, p.9).

The PHPP includes tools for calculating the U-values of components with high thermal insulation, calculating energy balances, designing comfort ventilation, calculating the heat load, summer comfort calculations, and many other useful tools for reliable design of passive houses (Pfluger 2005, p.81). The calculations of “Passive House Planning Package” are implemented in Microsoft Excel. This tool contains several worksheets for the building envelope (including walls, roof, ground, windows, and external doors), shading devices, and mechanical system components including ventilation and heating systems.

Climate Consultant

Climate Consultant is a graphic-based computer program that displays climate data including temperatures, humidity, wind velocity, sky cover, and solar radiation in both 2-D and 3-D graphics for every hour of the year. Climate Consultant also plots sun dials and sun shading charts overlaid with the hours when solar heating is needed or when shading is required. The psychrometric chart analysis shows the most appropriate passive design strategies in each climate, while the new wind wheel integrates wind velocity and direction data with concurrent temperatures and humidity. It can be animated hourly, daily, or monthly (U.S. Department of Energy 09.07.2008a).

GAEA

GAEA calculate the amount of heat gain (winter) and heat loss (summer) of the Earth Heat Exchanger (EHX) and supports the layout of EHX in the early stages of the planning of a building. It is based on analytic calculations of heat exchange between soil, systems of parallel buried pipes, and the air flow through the system. The heat exchange for the air flowing through the EHX and the corresponding change of temperature is calculated together with a lot of other data following from that.

The yearly variation of the soil temperature is taken into account, as well as the influence of nearby buildings or of the groundwater level, the fluctuation of the ventilation flow according to the occurring ventilation loads, and the course of outdoor temperature according to typical climatic data or measurements.

An optimization routine presents a choice of possible variations of the layout and their assessment concerning heat gains and economics (Heidt 21.06.2008).

Economic Evaluation (Oeko-Rat)

The program Economic Evaluation is used for calculating the economics of energy saving and renewable energies. This program evaluates the economic efficiency of an investment according to the capital value method. Any investment into energy saving measures usually consists of the acquisition or the replacement of a system.

Economic Evaluation considers the following parameters:

- Initial investment costs,
- Annual operating costs, increased by a given inflation rate
- Annual energy savings (also increased by a constant annual inflation rate which refers to energy costs),
- Energy costs, etc.

If any project does not pay back for the given parameters, the Economic Evaluation tool can determine conditions which would make the actual investment economically viable. These suggestions could include: initial financial support given by an institution, higher inflation rate for energy, or increased energy costs for the considered period of time (Heidt 10.05.2008).

Input Data

Input requirements for different energy simulation programs vary considerably. The input data generally describes climate, detailed architectural, constructional, mechanical, and electrical features of the building, as well as equipment operations and occupants. Simulation programs that determine the energy consumption of buildings require winter and summer design weather data or annual weather data files.

EnergyPlus, DesignBuilder and Climate Consultant need hourly weather files provided by U.S. Department of Energy in EnergyPlus weather format. The weather files of many cities of the world are available for these software tools and the hourly weather data of Tabriz and some other cities of the cold climatic region of Iran have been provided by the U.S. Department of Energy on request for use in present research.

This input weather data includes climatic factors for different sites at an hourly level including outside dry-bulb temperature, outside dew-point temperature, direct normal solar, diffuse horizontal solar, wind speed, wind direction, atmospheric pressure, solar altitude, and solar azimuth (DesignBuilder Software Ltd. 2008, p.311).

Climate Data Analysis

Psychrometric Analysis

The first step in environmental adjustment is a survey of climatic elements for the given location. However, each element has a different impact and presents a different problem (Olgyay 1963, p.11). The psychrometric analysis with climatic data shows the most appropriate methods of preparing interior comfort conditions (using active, hybrid and passive design strategies). The following graph shows the Psychrometric chart for Tabriz, based on dry-bulb temperatures.

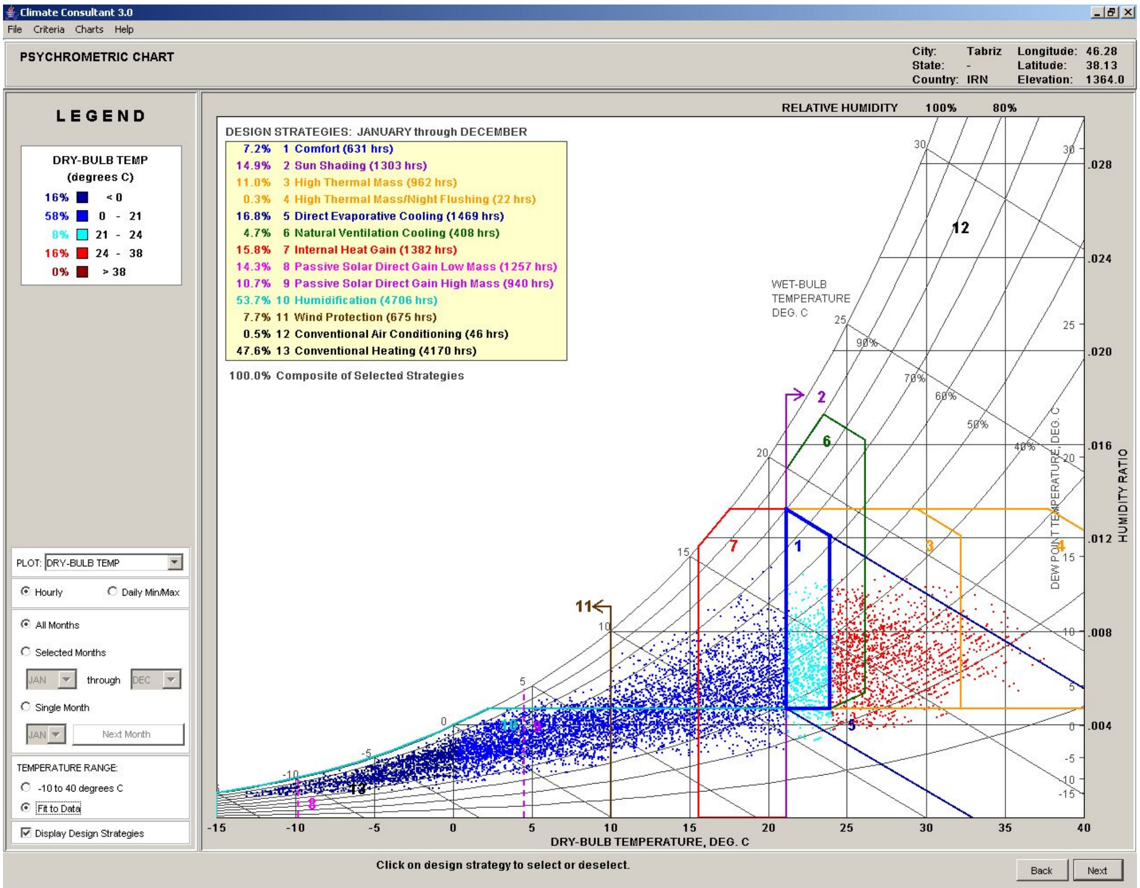


Figure 93: Psychrometric chart of Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

The psychrometric chart shows that heating is very important in Tabriz and the buildings need much more heating than cooling. It also shows that relative humidity in this city is low, especially in warm periods. According to this chart, the annual time percentages of different air temperatures are as follows:

Table 30: Annual time percentages of different air temperatures range in Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

Temperature	< 0°C	0 - 21°C	21 - 24°C.	24 - 38°C
Time percentage	16%	58%	8%	16%

Based on the psychrometric chart of Tabriz, the annual time percentage and the hours of different ways to supply comfortable conditions in buildings in Tabriz are stated in following table.

Table 31: Annual time ranges of the application of various design strategies in Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

Strategy	Time	
	Percent	Hour
Comfort	7.2	631
Sun shading	14.9	1303
High thermal mass	11.0	962
High thermal mass/ night flushing	0.3	22
Direct evaporative cooling	16.8	1469
Natural ventilation cooling	4.7	408
Internal heat gain	15.8	1382
Passive solar direct gain (low mass)	14.3	1257
Passive solar direct gain (high mass)	10.7	940
Humidification	53.7	4706
Wind protection	7.7	675
Conventional air conditioning	0.5	46
Conventional heating	47.6	4170

Heating

- Based on the psychrometric chart of Tabriz, for 74% of the year the temperature is under the comfort zone and heating is needed. However, a part of this heating can be supplied without conventional heating strategies and instead through internal heat gain, passive solar direct gain, etc.

- Passive solar direct gain is very important for passively heating the buildings in Tabriz and can be used for about 25% of the year.

- Internal heat gain can supply the comfortable conditions for 15.8% of the year.

- The buildings in Tabriz must be protected against cold winter winds 7.7% of the year.

Cooling

- According to the psychrometric chart of Tabriz, for 14.9% of the year shading must be used for windows during the day in order to prevent solar radiation from entering the indoor spaces.

- Natural cooling can be used for about 4.7% of the year.

- Because of the low relative humidity in Tabriz, passive and active evaporative cooling can be used for cooling the houses in summer. Evaporative cooling can be used during 16.8% of the year and this is almost the total time cooling is needed in Tabriz. Therefore, total cooling needed in Tabriz can be supplied through evaporative cooling. It is only during 0.8% of the year (70 hours) that evaporative cooling can not be used to cool the buildings in Tabriz.

- Based on the psychrometric chart, the capacity of building mass and materials to store heat for cooling purposes is very vital in Tabriz. High thermal mass is needed for 11% of the year.

Temperature Timetable Plot

The following figure shows the timetable plot of dry bulb air temperature during different months and time of day (also the time of sunrise and sunset) in Tabriz. Based on this figure, the air temperature is below the comfort zone throughout January, February, March, November and December. Therefore, during these months, the internal and external heat gain must be as high as possible and heat loss must be as low as possible.

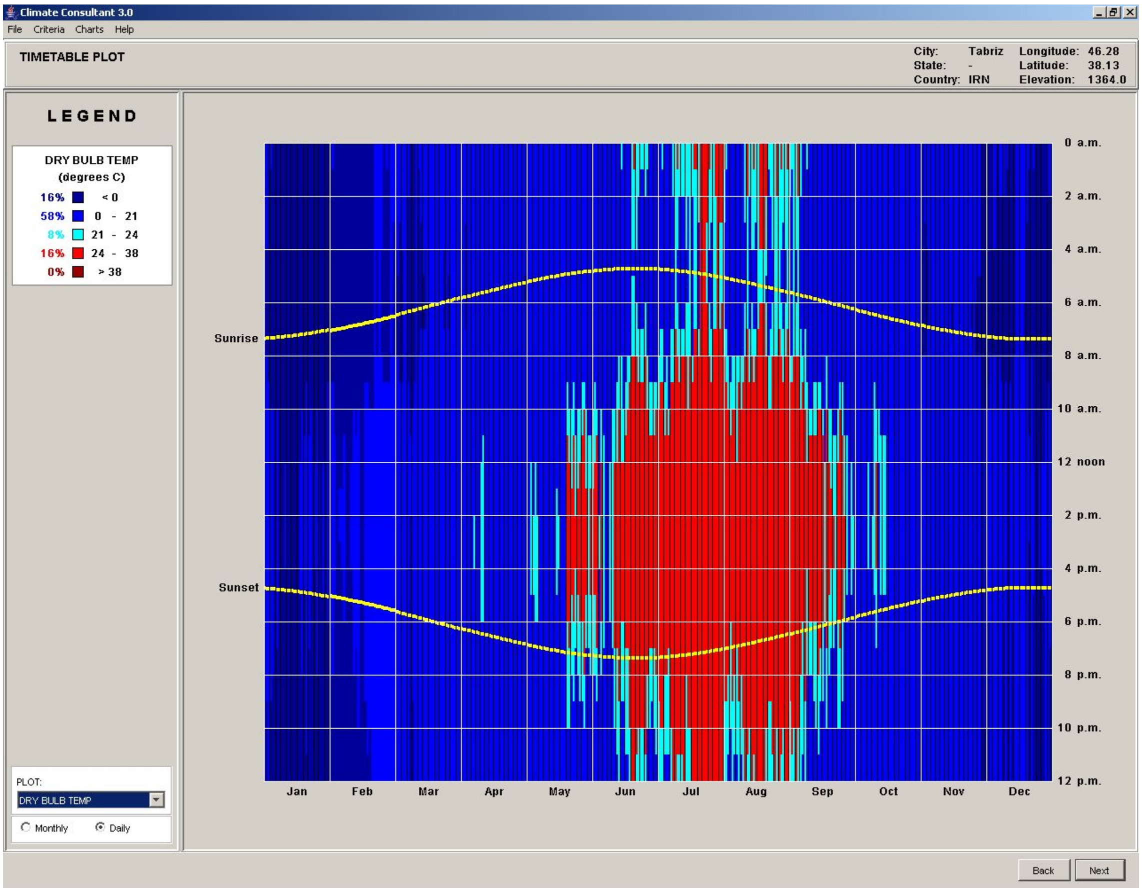


Figure 94: Time table chart of Tabriz, Source of Weather Data: U.S. Department of Energy 14.01.2008b

It shows also that the air temperature in July and August between 10am and 8pm is between 24 and 38°C. During this period, cooling is required and the internal and external heat gain must be as low as possible.

According to this timetable, the air temperature throughout the year is generally lower before noon than after. In winter, more solar heat gain is required in the morning than in afternoons and thus the building orientation must be turned from true south to several degrees east of south[1].

In summer the air temperature in the afternoon and early evening is higher than before noon. For example, the air temperature during July and August between 20:00 and 22:00 is higher than between 8:00 and 10:00. Therefore, protecting the building and especially its glazed surfaces against solar radiation in summer is much more important in afternoon than in the morning. The west-facing walls and windows also have more disadvantages in summer than those facing east. Shading on the west-facing walls and windows (via vegetation, suitable shading devices, etc.) is more important than east-facing windows.

Sun Chart and Sun Shading Chart

Throughout the period during which the air temperature is greater than the cooler temperature border of the comfort zone, no solar radiation is needed and glazed surfaces must be shaded. This period covers 14.9% of the year; therefore, shading of windows is very important in Tabriz. Shading is needed during different times of the day and year. The ability to shade the windows only when needed is essential to reduce cooling energy and simultaneously not to increase the heating energy demand.

Based on sun charts and sun shading charts of Tabriz, throughout January, February, March, November and December, in the mornings during May and April, and before 10am in June, August and September, solar radiation is needed and the windows must not be shaded. In the afternoon (and some morning hours) of June, July, August and September shading devices are needed. The size of fixed shading devices must be calculated, and adjustable shading devices must be controlled so that windows are shaded only during the necessary times and not shaded when solar radiation is required.

The following graphs show the sun chart of Tabriz (from 21 December to 21 June, and 21 June to 21 December) and present the times in which shading is needed.

[1] - The optimal degree of eastward rotation of the building from south, must be determined via simulation.

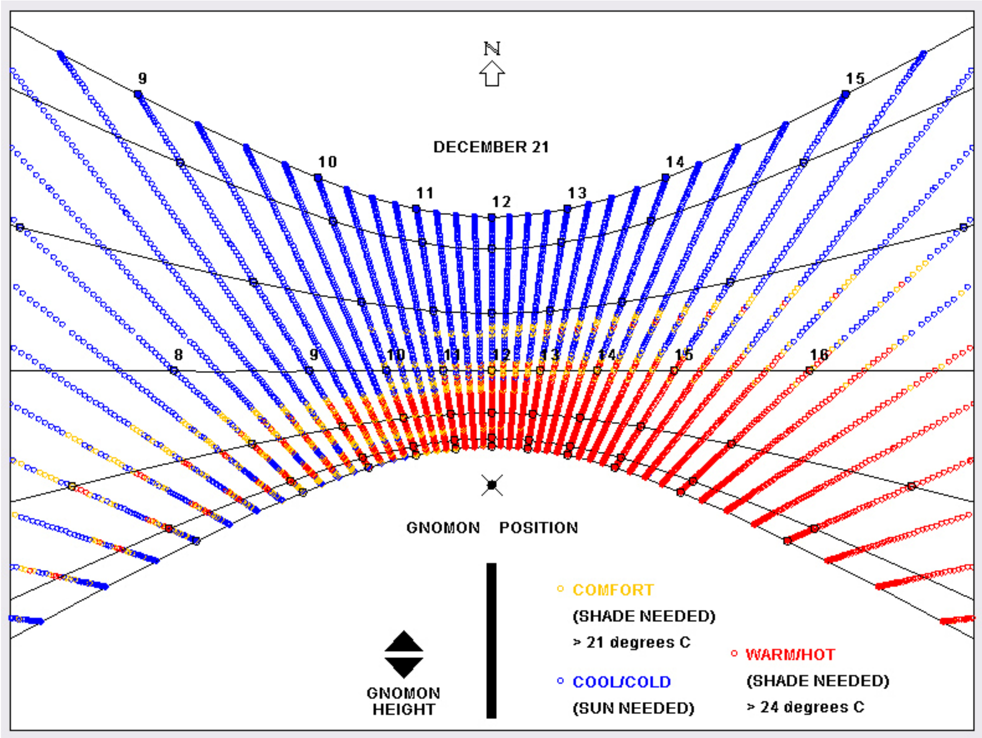


Figure 95: Sun chart of Tabriz (June 21 to December 21), Source of Weather Data: U.S. Department of Energy 14.01.2008b

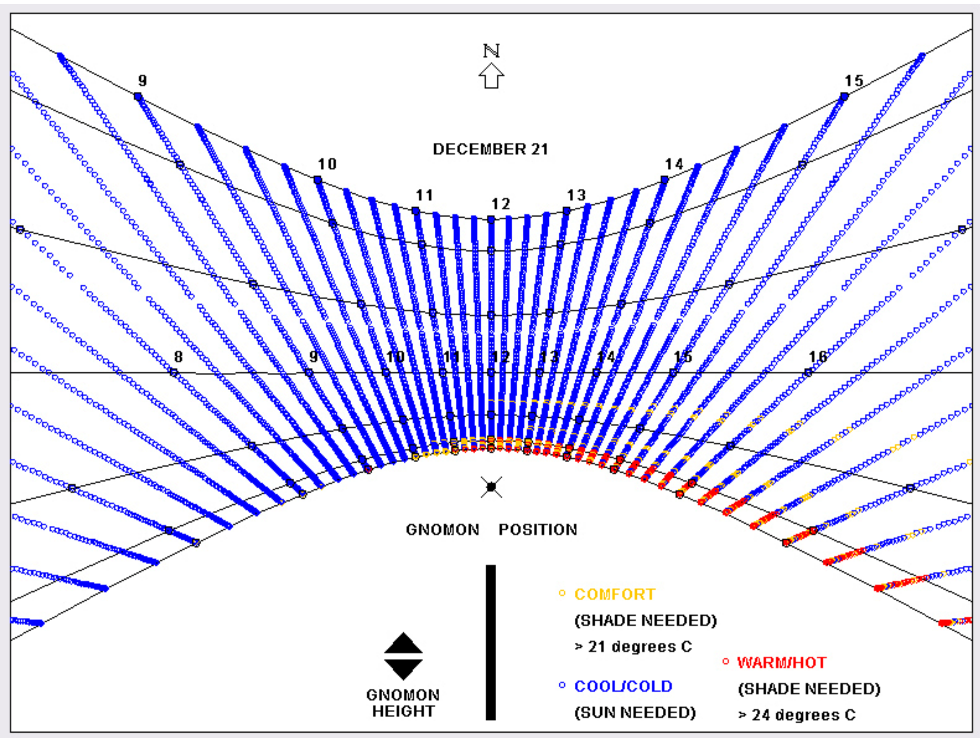


Figure 96: Sun chart of Tabriz (December 21 to June 21), Source of Weather Data: U.S. Department of Energy 14.01.2008b

The following graphs show the sun shading chart of Tabriz from 21 December to 21 June, and 21 June to 21 December.

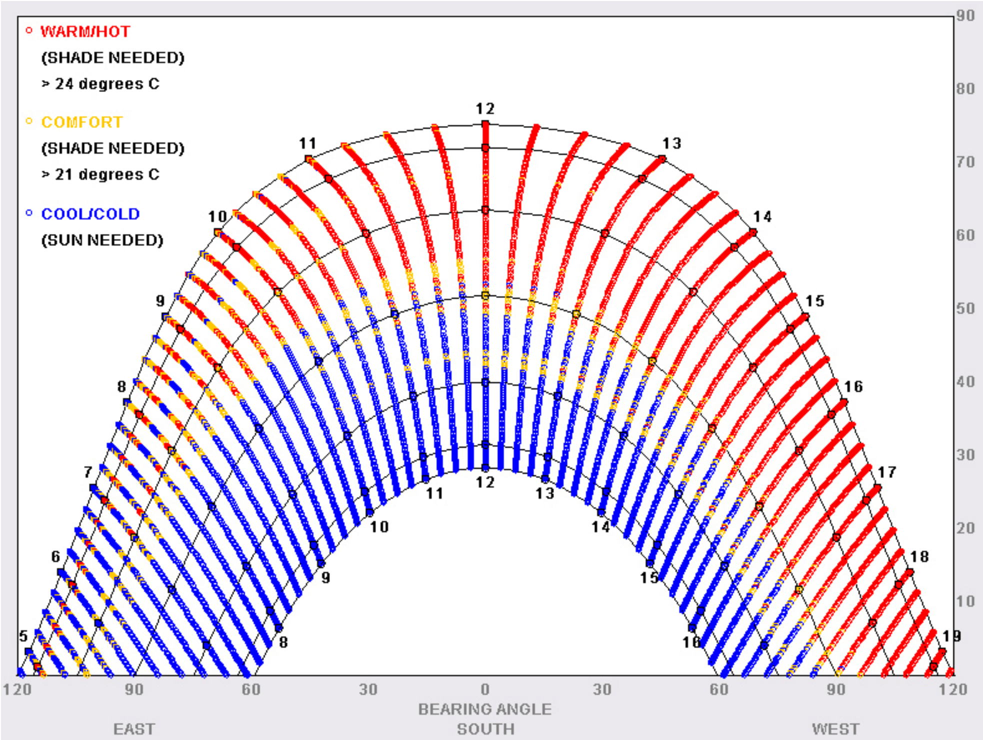


Figure 97: Sun shading chart of Tabriz (June 21 to December 21), Source of Weather Data: U.S. Department of Energy 14.01.2008b

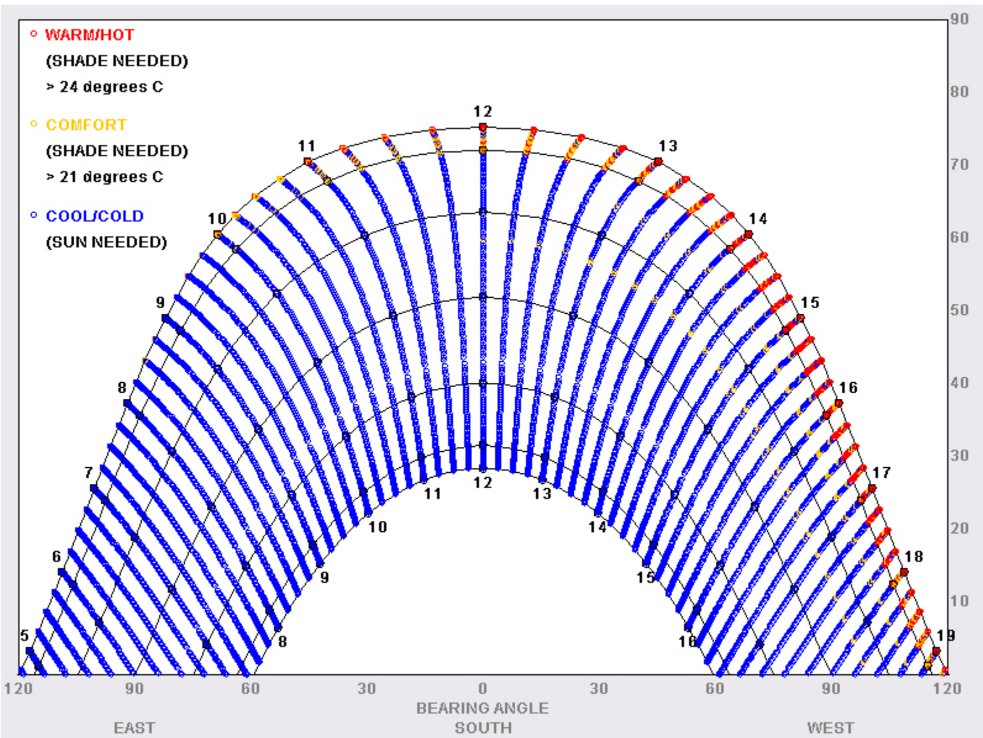


Figure 98: Sun shading chart of Tabriz (December 21 to June 21), Source of Weather Data: U.S. Department of Energy 14.01.2008b

Passive Houses in the Cold Climatic Region in Iran

Introduction

To study the effect of architectural design and other factors on the amount of energy required by passive houses situated in Iran's cold climatic region (the city of Tabriz), an existing three-story house in Tabriz has been chosen. This house is imagined as a passive house with the main characteristics of passive houses (such as triple glazed windows, ventilation systems with heat exchangers, 0.6 air change per hour) and with 35cm of roof insulation and 24.2cm of wall insulation.

Four alternative houses with matching site and built areas are designed which improve in energy efficiency from building 1 to building 5. Then, by comparing the amount of energy needed by each building under the same conditions[1], the design factors that affect the energy need of these buildings are found. Because buildings numbers 5 and 4 require the least energy, these two buildings are compared in order to make more detailed simulations. This comparison studies the effect of different factors on energy need and finds the optimum insulation thickness of passive houses in Iran.

"Passive House Planning Package" software is used for the simulation of these buildings, and the output data, combined with some other data, is used to analyze these houses and their energy requirements. In order to analyse the data more easily, diagrams are used to graphically present the findings. Although "Passive House Planning Package" has an Excel sheet dedicated to summer cases, the main function of this software is to calculate the heating energy consumption of passive houses. Therefore, in this part of the simulation and analysis, only the heating energy consumption of passive houses in the cold climatic region of Iran are calculated. The results are based only on heating energy demand.

Most of Iran's individual low rise houses are row houses and have neighbouring buildings, therefore, however the amount of insulation of the simulated buildings are calculated both with and without neighbouring buildings. Iranians do not heat all rooms of their houses during the entire winter. Instead, they heat only the rooms which are continuously being used. Adjoining space of the

1 - In all simulation and calculations the following conditions remain constant:
- Use of the same heat exchanger with 80% thermal efficiency.
- The same city and climatic conditions.
- The same amount of internal heat gains from house appliances, lights and occupants.
- Use of triple glass windows with insulated frames (U-factor: 0.80 W/m²K), unless stated otherwise.
- The energy requirements of buildings is 15 kWh/ m²a for all simulations and comparisons other than those of the energy requirement itself.
- In all buildings, the amount of insulation material is calculated for one residential unit of a house.
- In the east and west sides of the buildings, there are two neighbouring buildings. The amount of insulation material is calculated under two conditions (with and without neighbouring buildings).
- The designing of the buildings complies with Iran's architectural and cultural rules.
- All of the simulated buildings are south-facing.
- Floor insulation thickness is kept constant.

neighbouring buildings can be either controlled or uncontrolled. Therefore, both neighbouring buildings are imaged as uncontrolled spaces.

The amount of heat loss from the thermal envelope adjoining an uncontrolled space is about half that of other envelope components. Therefore, in calculating the amount of insulation material for the elements with neighbouring buildings, the thickness of insulation material of walls adjoining uncontrolled spaces (such as staircases) and neighbouring buildings is imagined to be half the insulation thickness of other walls calculated by simulation.

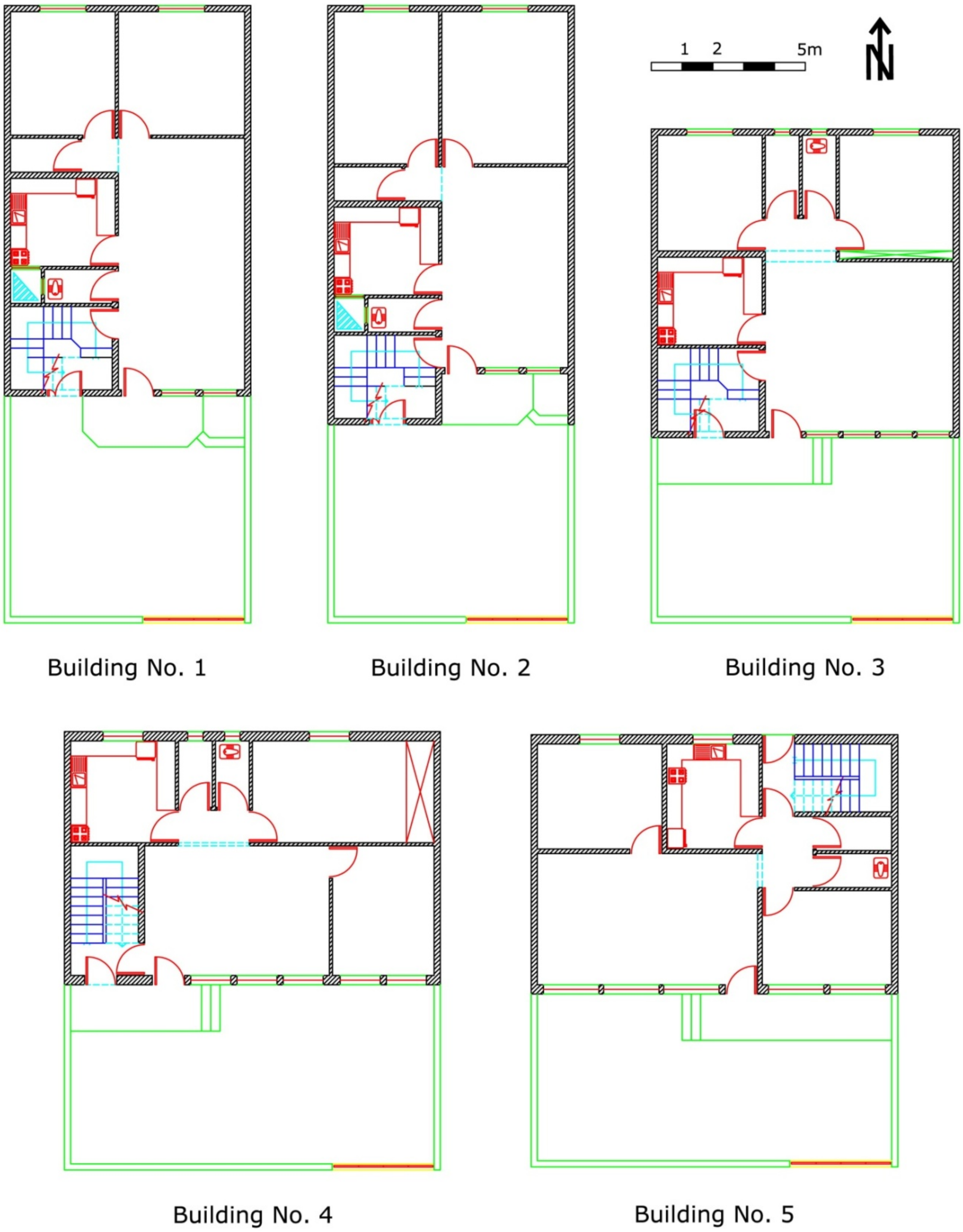
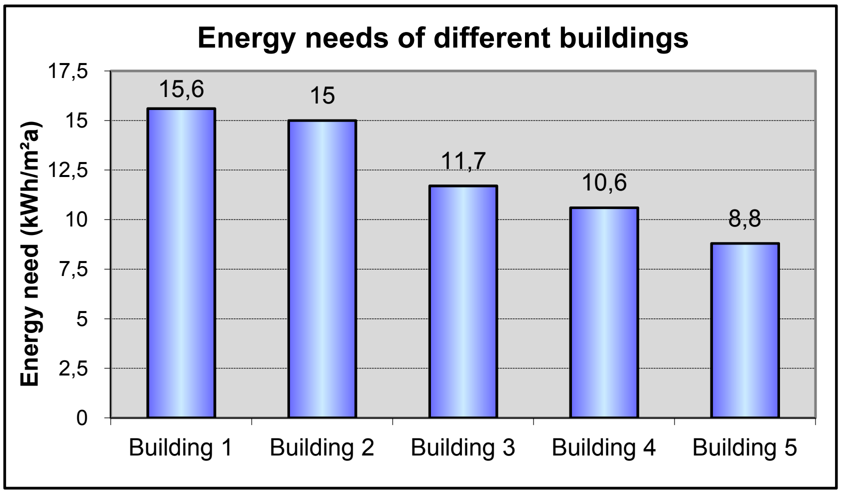


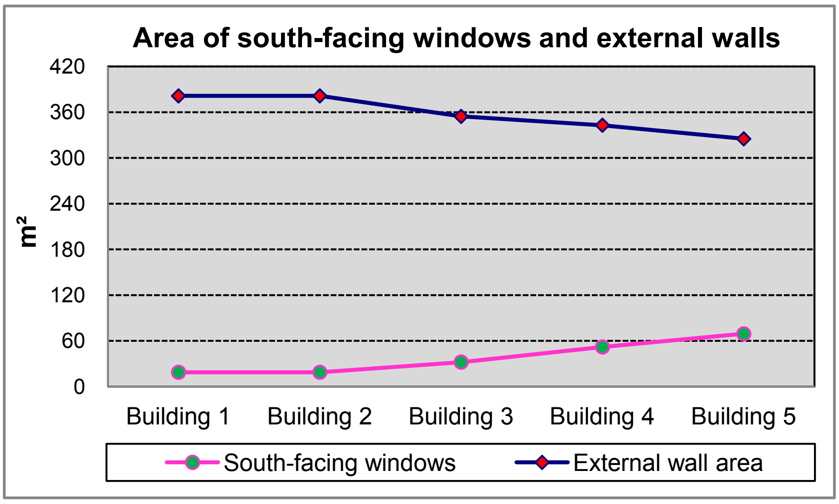
Figure 99: Simulated, existing and designed buildings

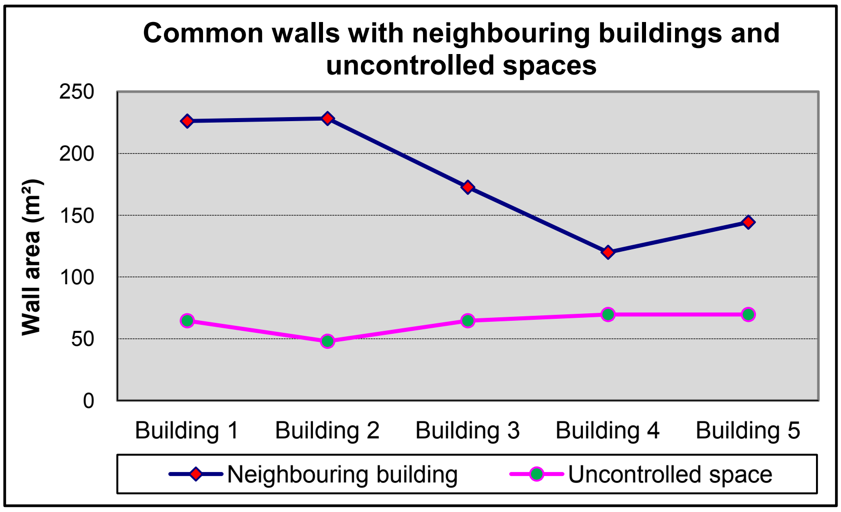
Energy Demand of Buildings with the Same Insulation

The following graph compares the energy needed by different buildings with the same insulation thickness (24.2cm wall insulation, 35cm roof insulation). This graph shows how the energy need decreases from buildings 1 to 5.



In the following graphs, different characteristics of these building are compared in order to find the factors which affect the energy consumption of these buildings.



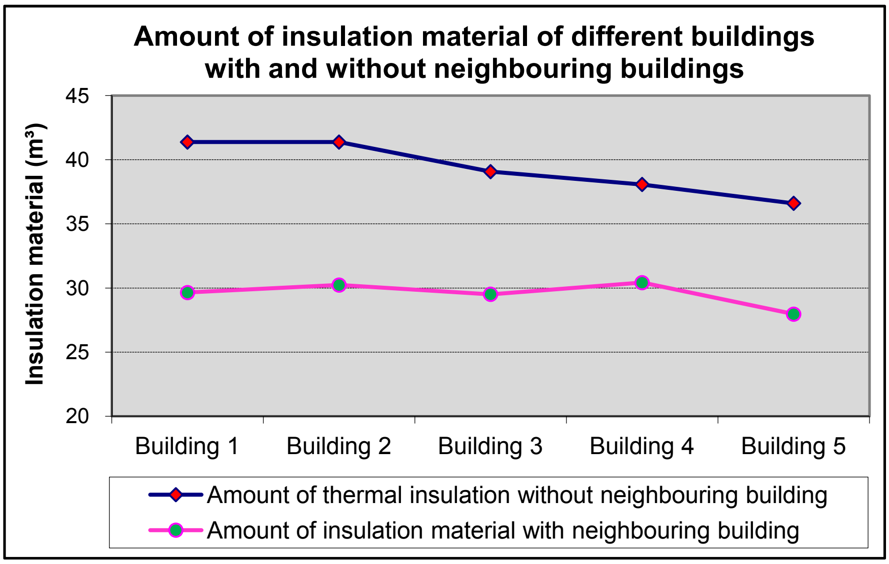


The reasons for the reduced energy consumption of these buildings are:

- Increasing the length (and therefore the area) of the south wall
- Increasing the south-facing windows
- Increasing the compactness of the building
- Keeping the southern side of the building free from uncontrolled and unimportant spaces, thus increasing the usable south wall area and south-facing windows
- Smaller amount of external walls.
- Locating living spaces to the south, as they are more frequently used and have higher temperature during the day, and organising bedrooms, less important spaces and non-living rooms to the north, east and west.

These factors show that a building's design can strongly influence its energy requirements. To have a passive house we have to design a climate responsive house and then further reduce its energy need with the use of insulation, a heat exchanger, proper windows, and so on.

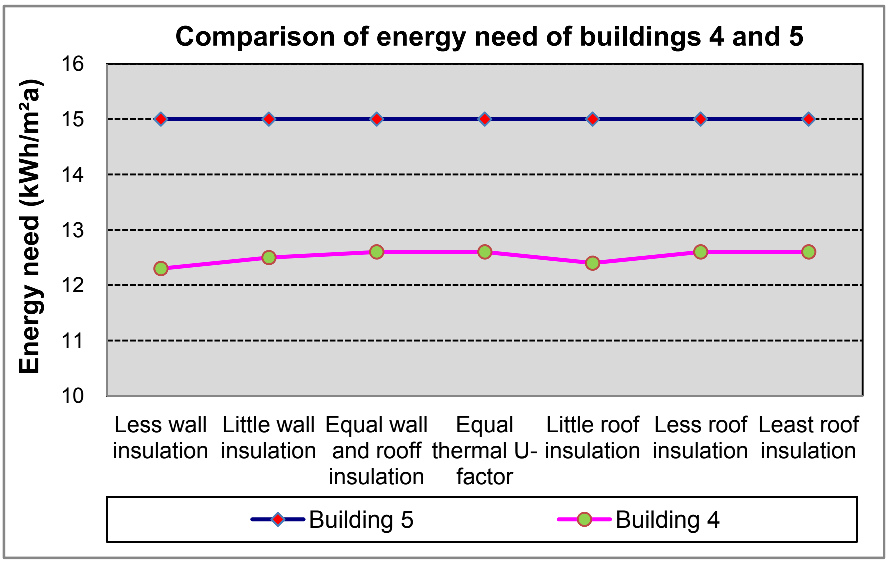
Although keeping the thickness of insulation material constant in all buildings, the amount of insulation material is reduced from buildings 1 to 5, because the area of opaque thermal envelope is reduced. The area of the external envelope in buildings 4 and 5 is almost equal, but building 5 has an increased window area and thus its external wall area is less than building 4.



Comparison of Buildings 4 and 5

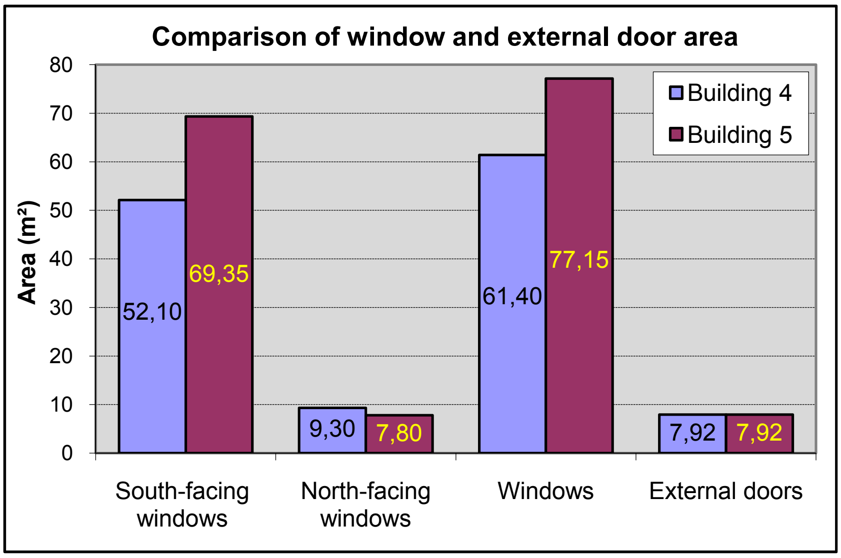
Comparison of Buildings 4 and 5 with Equal Insulation Thickness

The following graph compares the energy demand of buildings 4 and 5 with the same thickness of insulation material under different topics. It shows that in each case building 5 requires less energy than building 4.



A comparison of these two buildings shows that three factors make them different:

- South-facing window area of building 5 is more than building 4 (17.25m²).
- North-facing window area of building 5 is a little less than building 4 (1.5m²).
- External wall area of building 5 is less than building 4 (17.8m²).



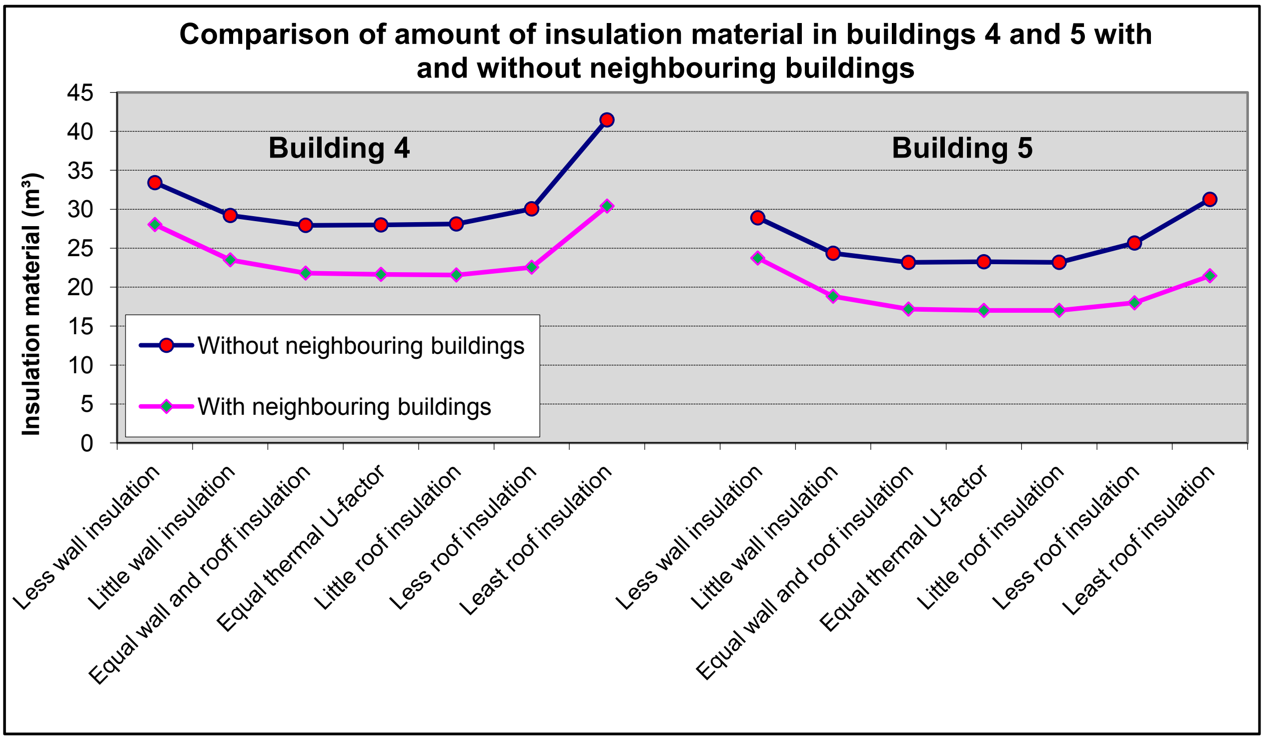
Some of the reasons why building 5 requires less energy than building 4 include:

- Increased south-facing window area and thus increased solar heat collection
- Reduced external wall area (due to increase in window area) and therefore, minimising heat loss through walls that have no heat gain.

Although building 5 has less energy need than building 4 (with the insulation thickness remaining the same), it requires less insulation material for the whole building because it has a larger window area and thus less external wall area than building 4.

Comparison of Buildings 4 and 5 with Equal Energy Needs

This diagram shows that the amount of insulation material (with and without neighbouring buildings) required by building 5 is, in each case, less than building 4 when they need the same level of energy (15kWh/m²a).



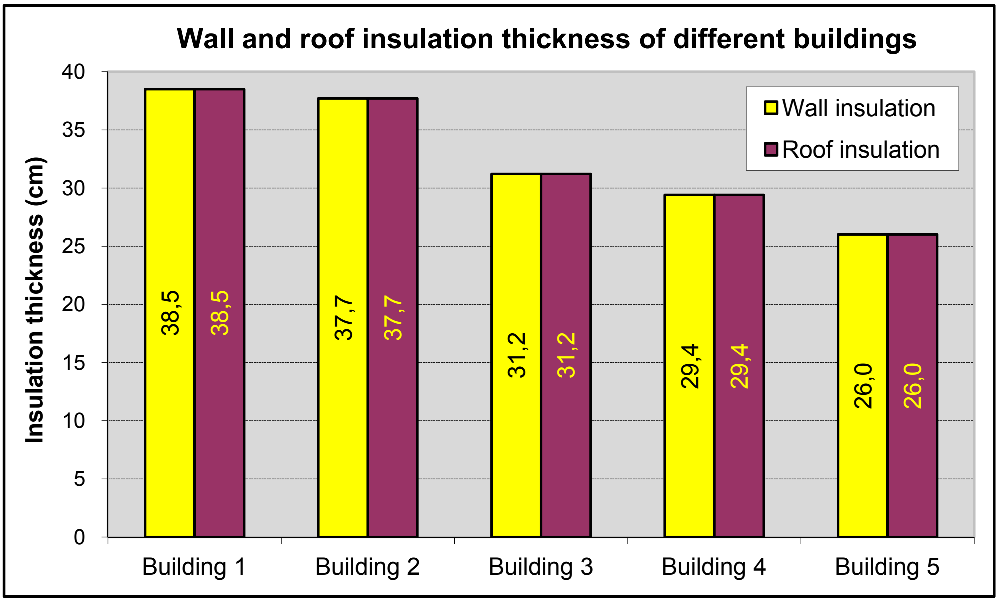
The reasons why building 5 requires less insulation material (compared with building 4) are:

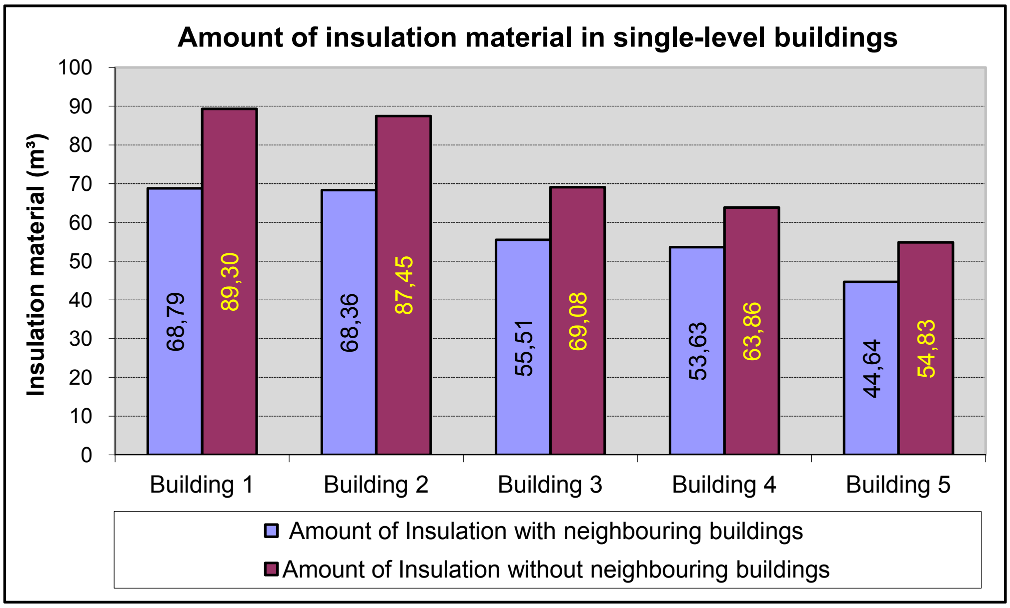
- The south-facing window area of building 5 is more than building 4, therefore reducing its energy need.
- The south-facing window area of building 5 is more than that of building 4, and therefore the external wall area (in need of insulation material) in the former is less than in the latter.

Effect of the Number of Stories on Insulation

Insulation Material of Single-Level Passive Houses

With the same amount of energy requirements (15 kWh/m²a), the wall and roof insulation thickness decreases from building 1 to building 5 from 38.5 to 26 cm. Therefore, the amount of insulation material (with and without neighbouring buildings) also decreases from building 1 to building 5.

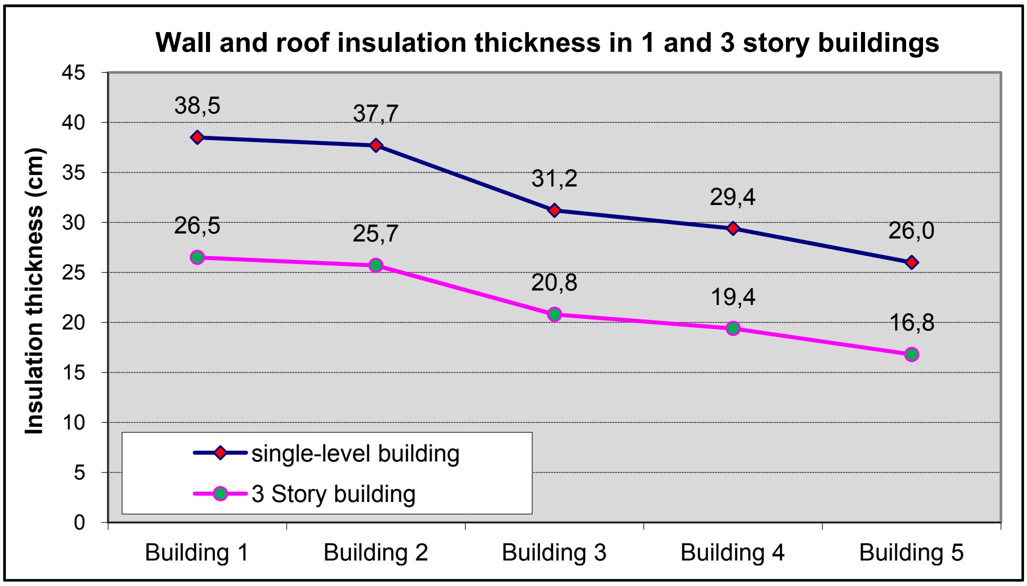




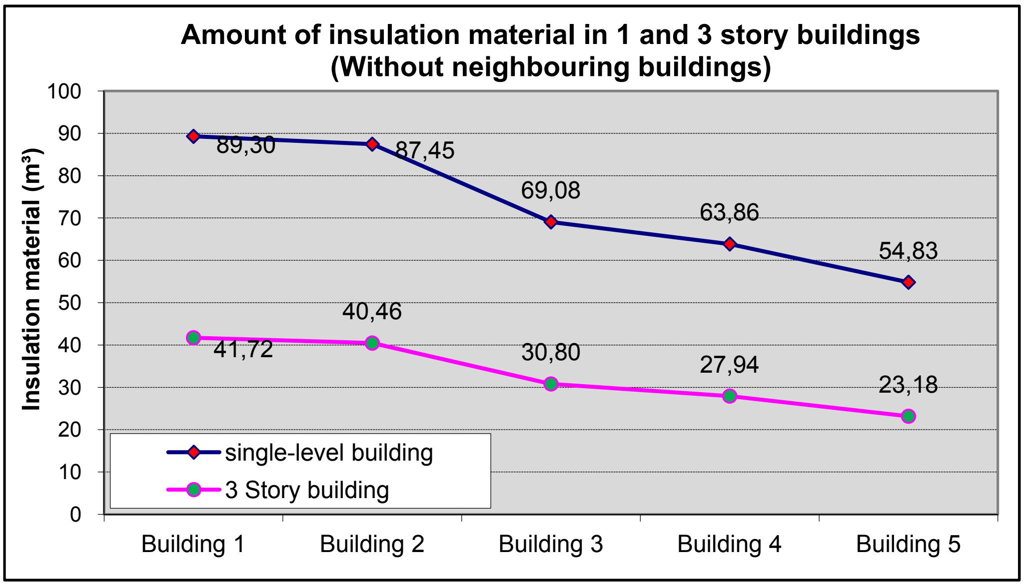
This shows that it is possible to construct a single-story passive house in Tabriz with 26 cm (or less) wall and roof insulation thickness.

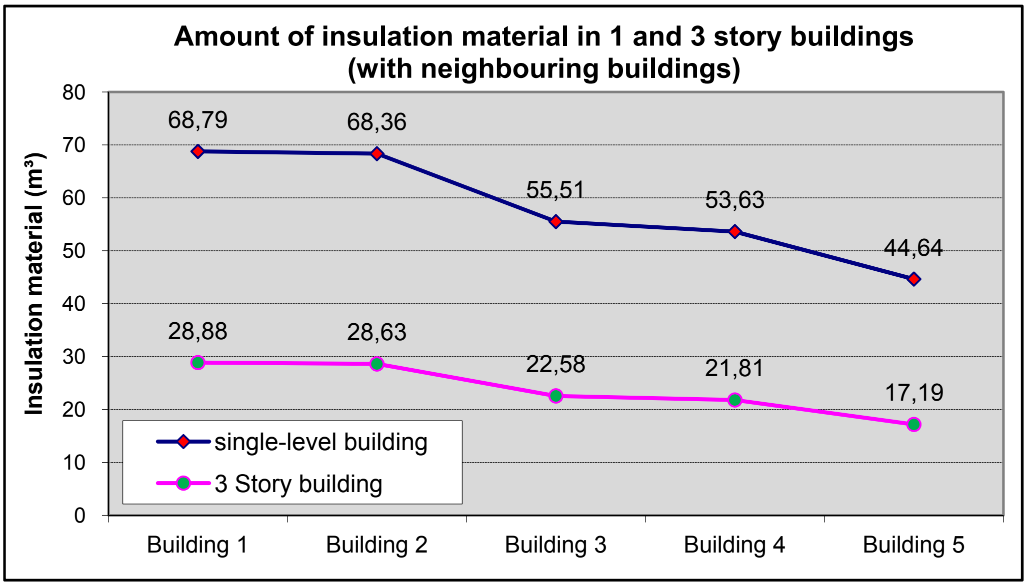
Insulation Material of 1 and 3-Story Passive Houses

In the different buildings (1 to 5), the thickness of wall and roof thermal insulation and thus the amount of insulation material for each single story of a 3-story residential unit is less than the insulation material required by a single-story building (with and without neighbouring buildings). Average insulation thickness in 3-story buildings is 33% less than in single-level buildings. The following graph also shows that it is possible to construct a 3-story passive house in Tabriz with 16.8 cm wall and roof insulation thickness.



The following graphs compare the amount of insulation material of 1 and 3-story buildings with and without neighbouring buildings.

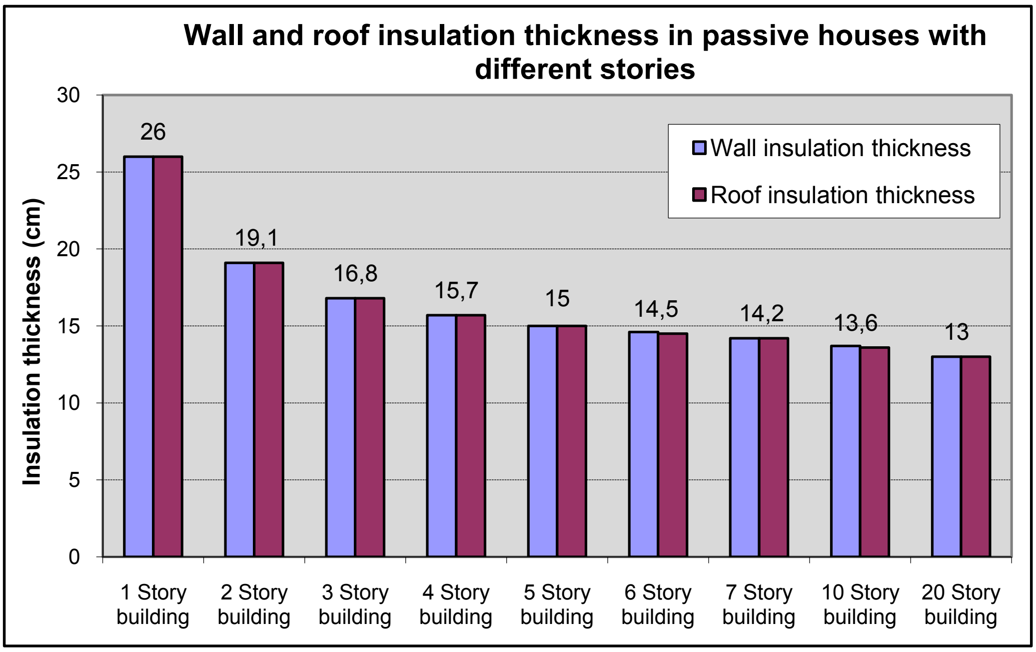




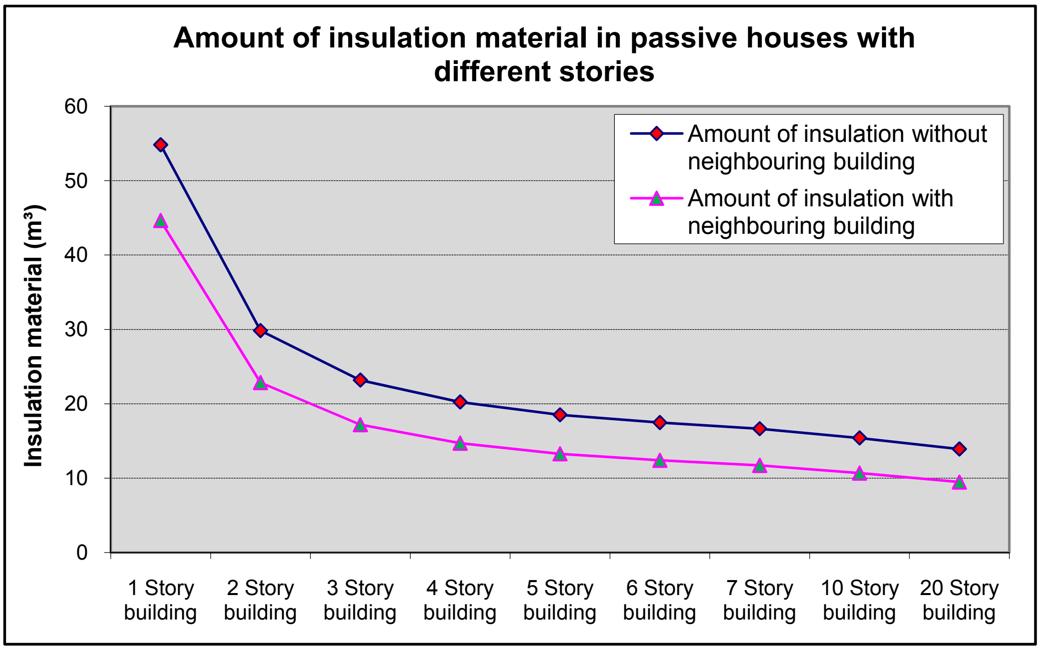
The amount of insulation material of a residential unit in 3-story buildings compared to a single-level building is reduced 55% without neighbouring buildings and 59% with neighbouring buildings.

Insulation Material of Multi-Story Passive Houses

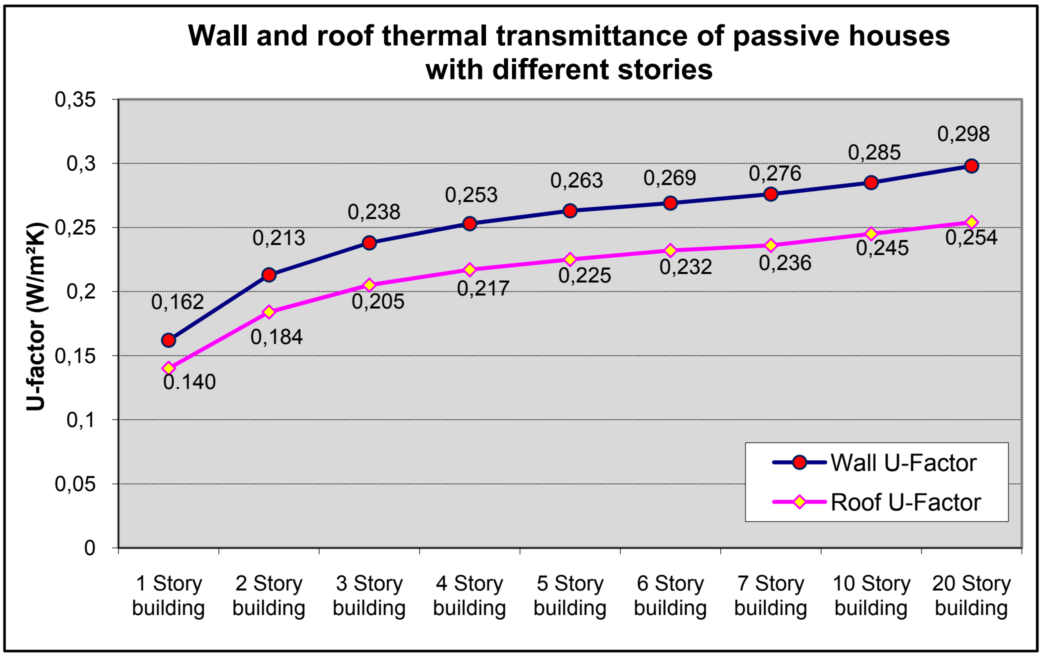
Simulation of building 5 with different stories (different residential units) shows that the more stories a multi-story passive house has, the less insulation material is required. Single-level building 5 needs a 26 cm wall and roof insulation thickness to be classified as a passive house, but this building with 20 stories needs only 13 cm thick of insulation material.



The amount of insulation material of passive houses will also decrease if the building has more stories.



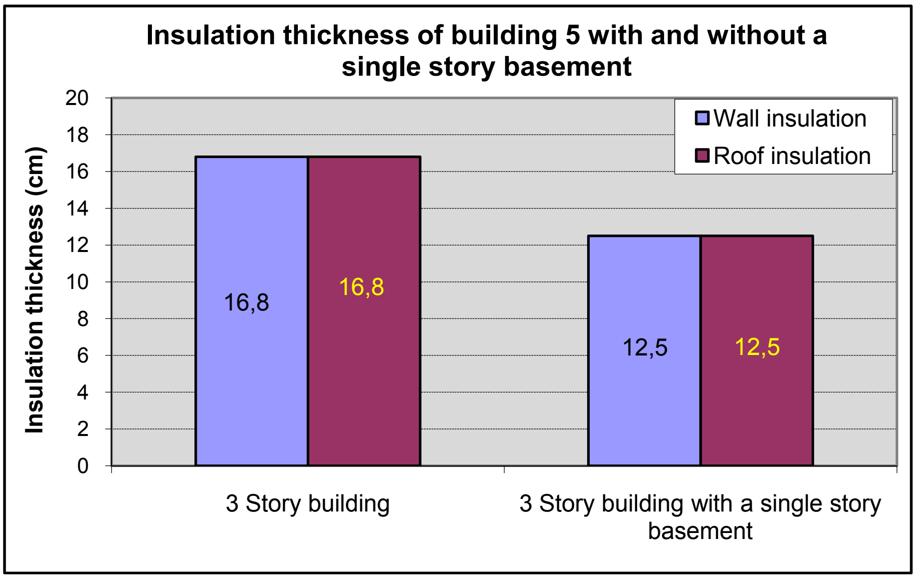
Single-level Building 5 must have a 0.162 and 0.140W/m²K wall and roof U-factor to be classified as a passive house, while for a same building with 20 stories they change to 0.298 and 0.254 W/m²K.



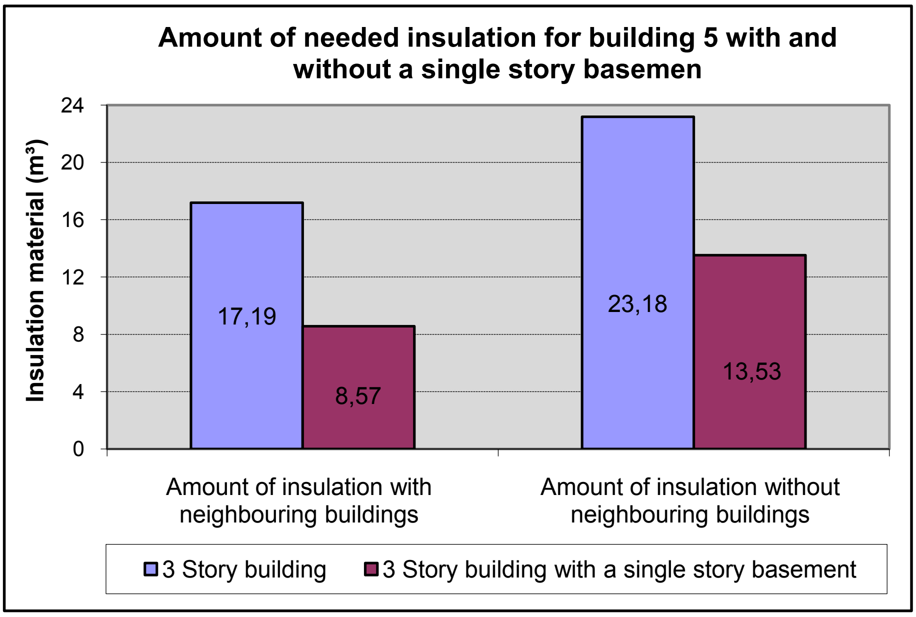
The reason for the increased U-factor and decrease in insulation is that, in multi-story buildings, only the top story losses heat from the roof and only the first story has heat loss from the floor.

Comparison of Buildings with and without a Basement

Comparison of building 5 with and without a single story basement shows that if one story of a passive house is located underground as a basement story, the thickness and amount of insulation material will effectively decrease. In this building, the insulation thickness without a basement is 16.8 cm and it decreases to 12.5cm if the same building has a single story basement.



The amount of insulation material of this building will also decrease if 1 story of this building is located underground as a basement.



In a basement story, the amount of heat loss from walls and floor is less than in other stories. This is because ground temperature is greater than air temperature in winter and less in summer. The ground temperature is nearer to the comfort zone than air temperature, therefore in the basement, comfortable conditions for both winter and summer are achievable with the use of little energy. Therefore, the basement story reduces the building's energy requirements.

Simulation shows that locating part of a building underground reduces the amount of energy needed and thus the amount of insulation material. These basement stories can have a basement courtyard with a floor is located below the earth's surface. Optimal orientation is south to maximise day lighting and solar heat gains.

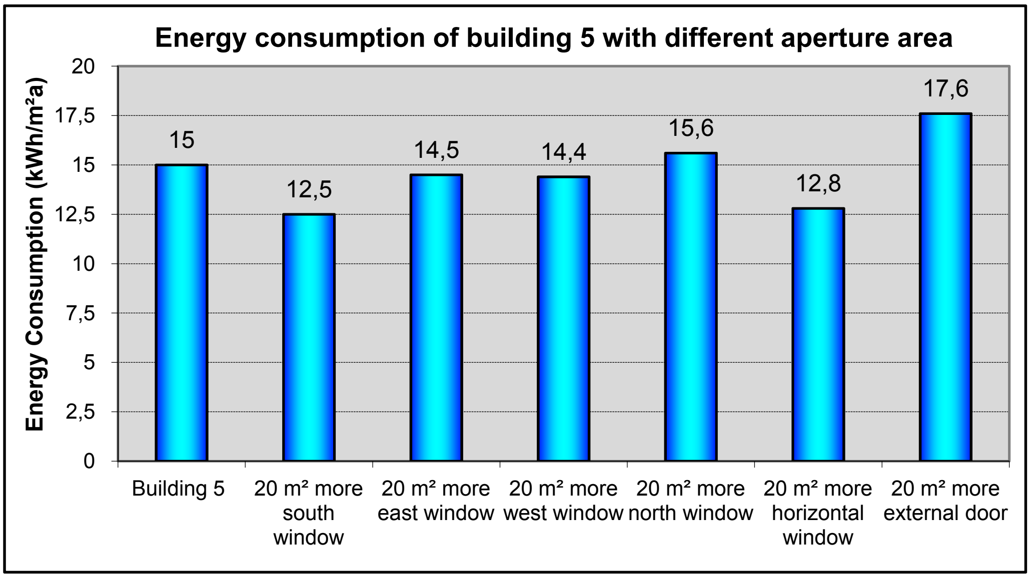
Building Components of Passive Houses

Windows

Effect of Triple Glazed Windows on Energy Need

The following diagram shows that by increasing the south-facing and horizontal windows, the energy needs of a building reduce effectively. Therefore, south-facing, horizontal windows have a positive energy function.

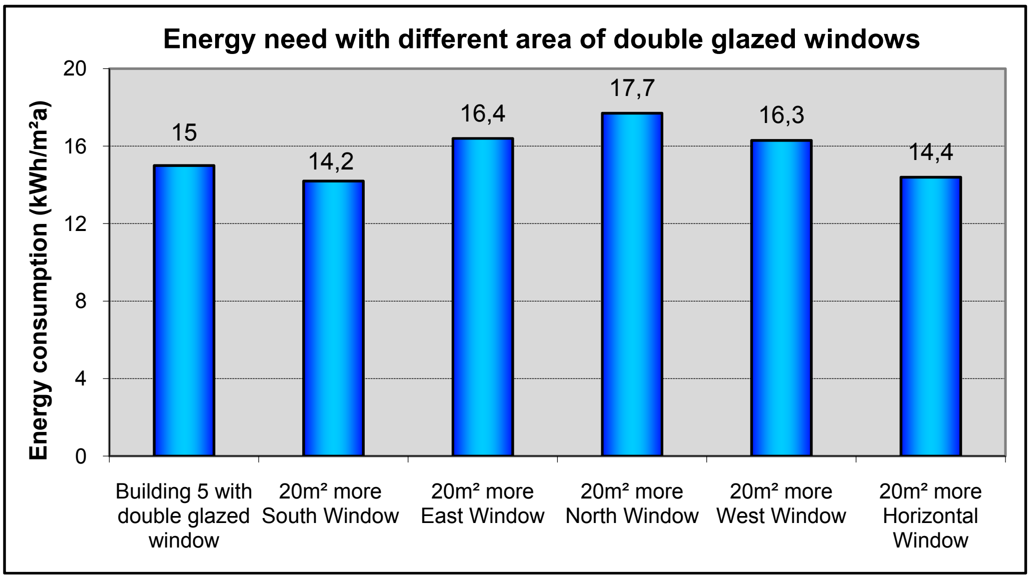
South-facing windows receive little energy in summer and control of their energy gain via shading devices is easy. Therefore, passive houses must have as many south-facing windows as possible. Although horizontal windows have positive energy functions in winter, they can also gain a lot of energy in summer and control of them with shading devices is difficult.



Increasing the area of east- and west-facing windows slightly reduces the amount of energy needed and in winter, they have a positive energy function. However, these windows can gain a large amount of energy in summer and this can cause overheating. Therefore, east and especially west-facing windows must not be used in large areas. Increasing the north-facing window area increases the amount of energy needed, thus these windows must be used as little as possible. Increasing the area of external doors also effectively increases the amount of energy needed and has a very negative energy function. Therefore, external doors must be minimised.

Effect of Double Glazed Window on Energy Need

It is possible to have a passive house with double glazed windows. Using quantity of insulation material as a measure of energy efficiency and building 5 as a sample case, the effect of double glazed windows is analysed.

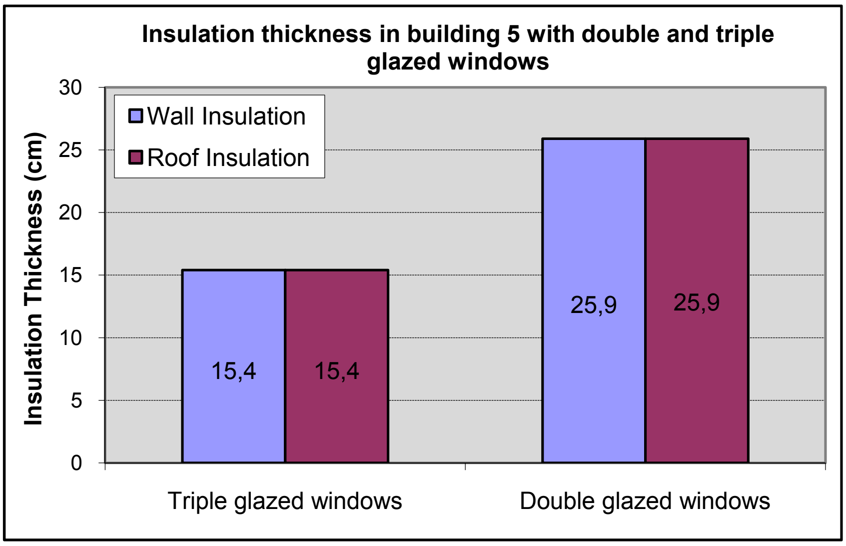


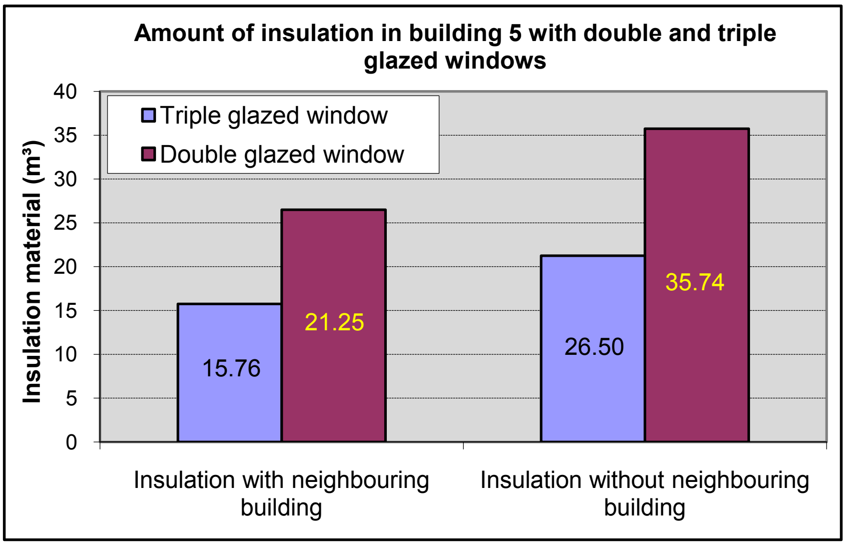
The amount of insulation required for building 5 with double glazed windows increases by a factor of 1.4 in the same building with triple glazed windows. In this case, the thickness of wall and roof insulation with triple glazed windows is 19.5cm and it increases to 24.5cm with double glazed windows.

Simulation shows that only south-facing and horizontal double glazed windows have a positive energy function. But west, east and north facing windows have more heat loss than solar heat gain. Therefore, if double glazed windows are used in passive houses of Tabriz, the west, east and north-facing windows have to be used as little as possible.

Comparison of Double and Triple Glazed Windows

Triple glazed windows have less heat loss in comparison with double glazed windows. Although double glazed windows have a higher solar heat gain coefficient and thus gain more solar heat, they are much less energy efficient, because they lose significantly more heat than triple glazed windows. Building 5 with triple glazed windows requires 15.4cm wall and roof insulation thickness to have 15kWh/m²a energy consumption but with double glazed windows it requires 25.9cm insulation to maintain the same energy consumption.



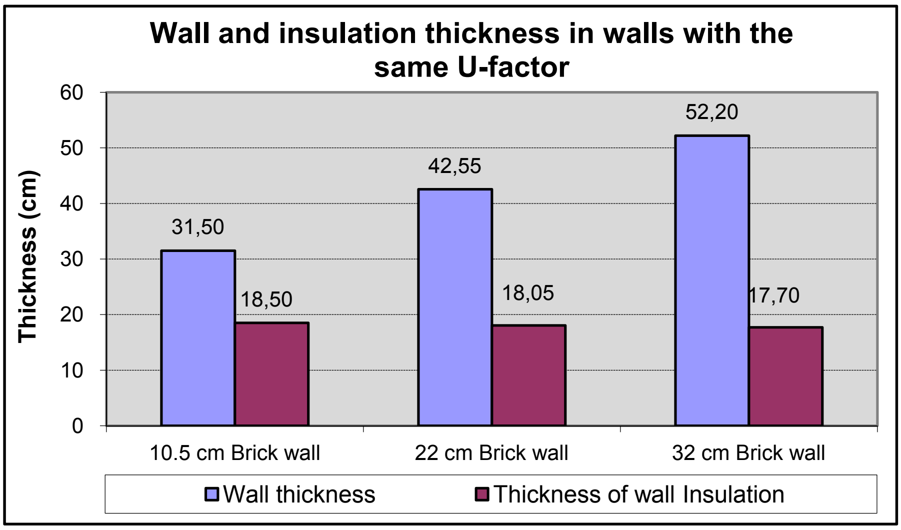


The last diagram compares the amount of insulation material required by building 5 (with and without neighbouring buildings) with double and triple glazed windows. This building needs significantly more insulation material with double glazed windows than with triple glazed windows.

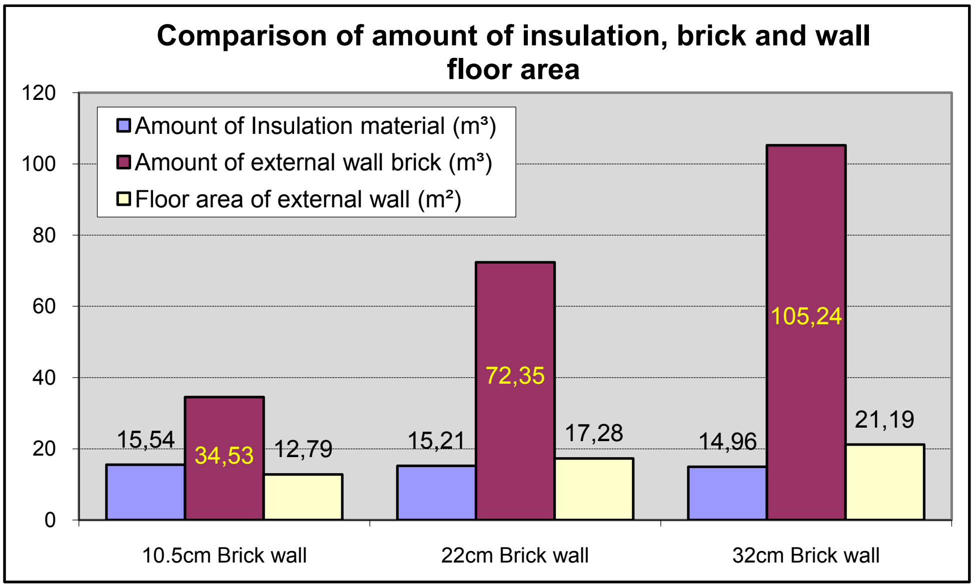
Use of Conventional Masonry Materials for Walls of Passive Houses

Thickness of Brick Walls in Passive Houses

In this diagram, complete wall thickness including insulation material is compared in three walls with the same thermal U-factor. The diagram shows that with a 21.5cm increase in the thickness of a brick wall, the thickness of insulation material decreases only 0.78cm and the entire wall thickness increases 20.7cm.



The next diagram compares the amount of insulation material, amount of brick in the external wall, and the amount of floor area occupied by the wall thickness in a building with a constant energy requirement.

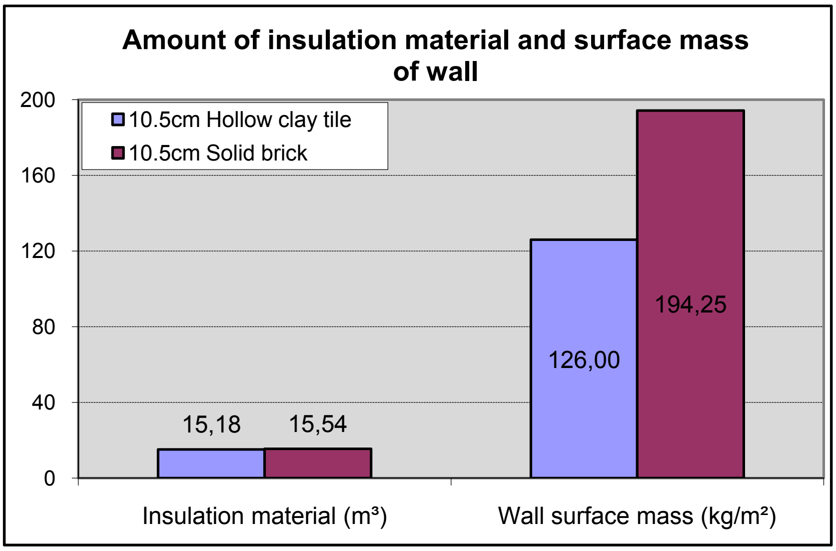


The diagram shows that, for a thick brick wall (32cm), the amount of brick increases by 70.70m³ in comparison to a 10.5cm brick wall, while the amount of insulation material decreases only about 1.20m³.

Using a thick brick wall (32cm) also increases the occupied wall floor area by about 8.06 m² and thus reduces the building's usable area. Because floor area is expensive in Iran, it is important to use as little floor area for walls as possible. Therefore, it is better to use thin brick walls (10.5cm) and add more insulation material, because it greatly reduces the amount of brick and wall thickness and only slightly increases the insulation material.

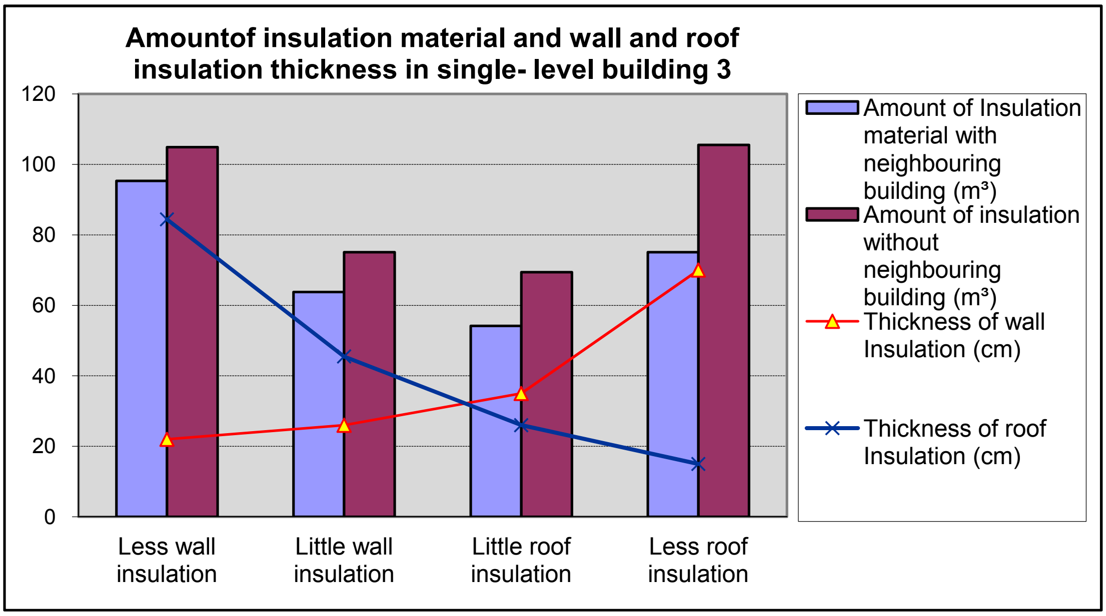
Use of Hollow Clay Tile or Solid Brick in the Walls

Comparison of light and solid brick in passive houses shows that the use of solid brick (with less thermal conductivity) increases the wall insulation thickness 0.5 cm and the amount of needed insulation 0.36 m³, but also increases the surface mass of external walls (68.25Kg/m²) and thus the quantity of thermal mass. Therefore, it is better to use solid brick than hollow clay tile in walls.

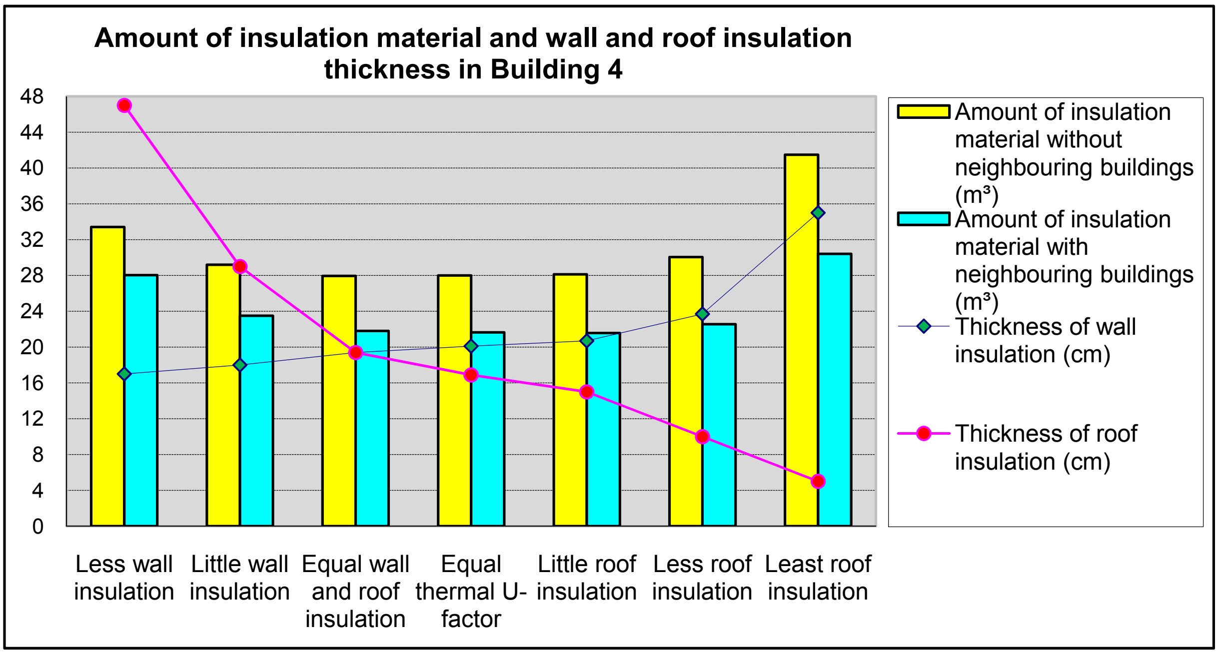


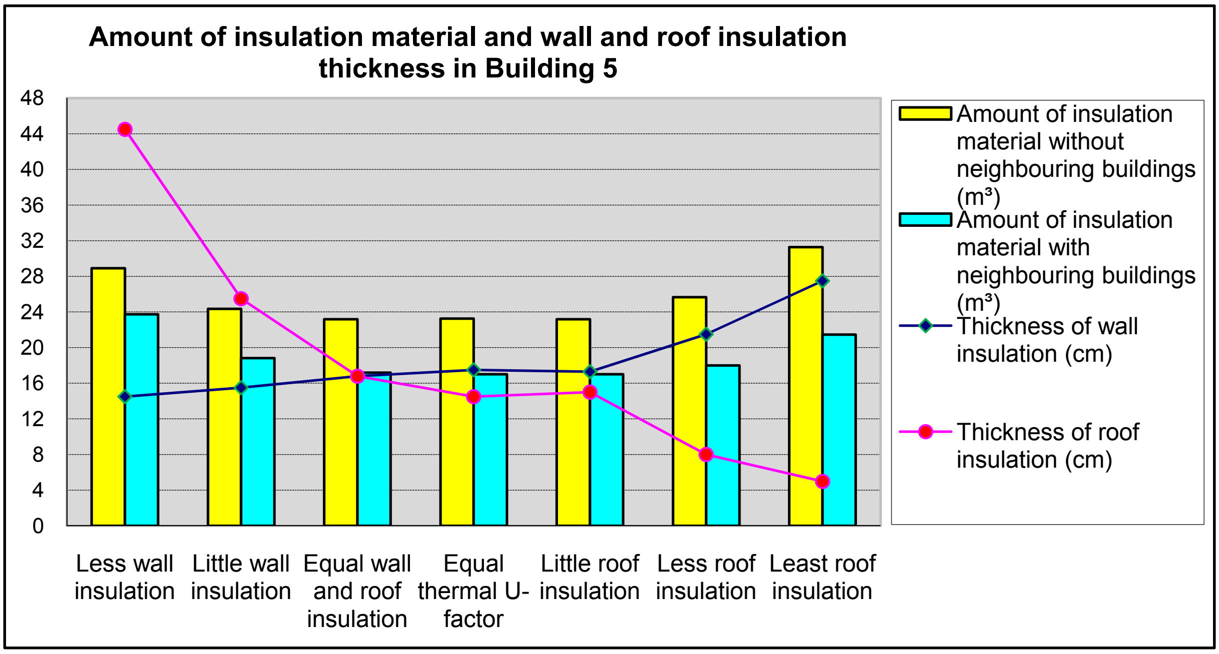
Proportion of Wall and Roof Insulation Thickness

Simulation of building 3 (single-level) with different thicknesses of wall and roof insulation shows that the building needs less insulation material when the difference between wall and roof insulation thickness is minimized.



Simulation of buildings 4 and 5 (3-story) with different thicknesses of wall and roof insulation shows that the greater the difference between the thickness of the wall and roof insulation, the greater the amount of insulation material required.





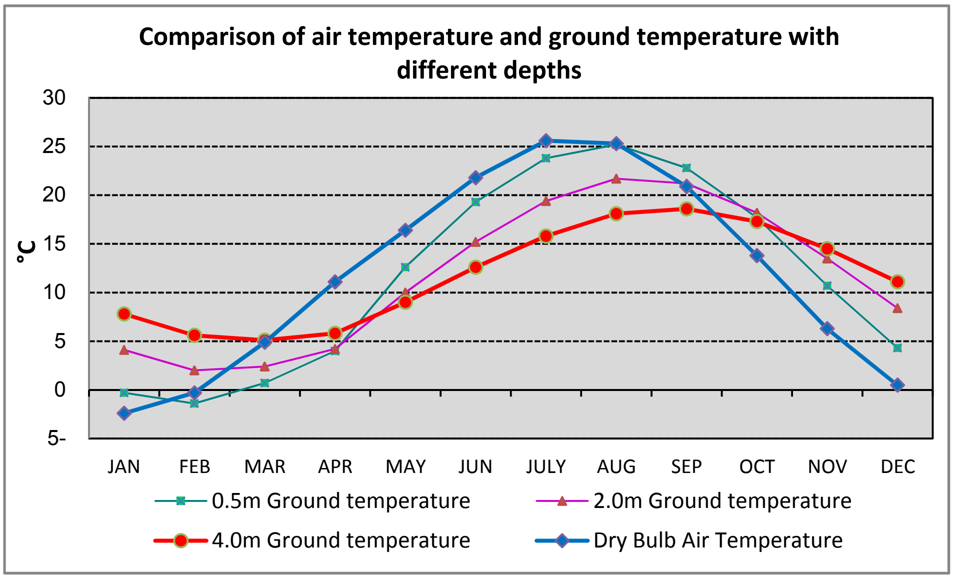
In a building without neighbouring buildings, if the walls and roof use insulation material the same in thickness, it needs less insulation material (simulation of buildings 4 and 5). In a building with neighbouring buildings, the least amount of insulation material is needed when the wall and roof have an equal U-factor (or if the thickness of wall insulation is slightly more than roof insulation).

Thickness of Insulation Material in Iran's Passive Houses

Single-level building 5 with and without neighbouring buildings needs 22.62 and 27.79cm wall and roof insulation respectively to be a passive house. Three-story building 5 with neighbouring buildings needs 12.46cm wall and roof insulation and without neighbouring buildings needs 16.80cm insulation to be a passive house. Based on these simulations, it is possible to have a three-story passive house in Iran with 12.46cm (or less) wall and roof insulation thickness or a single level passive house with 22.62cm thick insulation.

Depth of Subsoil Heat Exchanger

The depth of pipe systems in the earth (subsoil heat exchangers) must be, dependent on the climate and the temperature of the earth. The optimal depth is the level at which the earth's temperature is warmer in winter and cooler in summer. To determine the best depth for the subsoil heat exchanger, the ground temperature at different depths must be compared with the air temperature. This comparison in the city of Tabriz is between three depths (0.5, 2 and 4 meters) and shows that, 4m is the ideal depth for the underground pipe system. This is because the ground temperature at this depth, in comparison with the other two depths, has a more beneficial temperature difference to the air temperature during both heating and cooling periods.



Source: Based on data from Iran Meteorological Organization 07.01.2008 and U.S. Department of Energy 14.01.2008b

The ground temperature (especially at a depth of 4m), is not only more than the air temperature in heating periods, but is also less than the air temperature during cooling periods. Therefore, it can be used for both heating and cooling purposes. The only problem is during the months of April, May and June, when the air temperature is greater than the ground temperature and less than the comfort zone temperature. The average air temperatures for April and May are 11.1 and 16.4°C respectively, and ground temperatures at a depth of 4m are 5.8 and 9°C. During this period we have to increase the air temperature to within the comfort zone, but the ground temperature is less than the air temperature and thus, passing the air through the underground pipe system will further decrease the air temperature. Therefore, the use of a subsoil heat exchanger during the months mentioned above is a disadvantage. In this period, the air must not pass through the underground pipe system and must instead directly enter the ventilation system.

Table 32: Comparison of dry bulb and ground temperatures in Tabriz, Source: Based on data from Iran Meteorological Organization 07.01.2008 and U.S. Department of Energy 14.01.2008b

Climatic Factor		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ground temperature (°C)	0.5 m	-0.3	-1.4	0.7	4	12.6	19.3	23.8	25.2	22.8	17.7	10.7	4.3	11.62
	2.0 m	4.1	2	2.4	4.2	10	15.2	19.4	21.7	21.2	18.2	13.5	8.4	11.18
	4.0 m	7.8	5.6	5.1	5.8	9	12.6	15.8	18.1	18.6	17.3	14.5	11.1	11.78
Dry Bulb temperature (°C)		-2.4	-0.3	4.9	11.1	16.4	21.8	25.6	25.3	20.9	13.8	6.3	0.5	12

A Simulation of the Subsoil Heat Exchanger

In order to determine the amount of energy a subsoil heat exchanger can save in the houses of Tabriz, a sample subsoil heat exchanger[1] in this city is simulated. The heat exchanger is 52.20m long, and can be located in the court-yard of designed buildings. The following figures show the outdoor air temperature and the outlet air temperature of the subsoil heat exchanger throughout the year. They also show the amount of energy saving of the subsoil heat exchanger both in summer and winter.

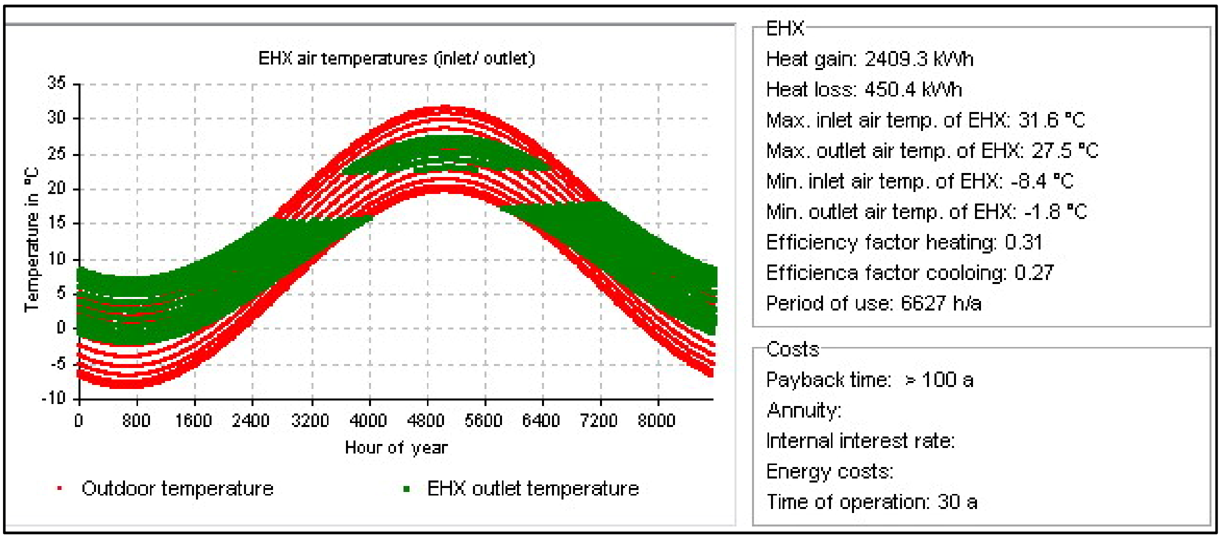


Figure 100: Inlet and outlet air temperature of subsoil heat exchanger throughout the year, and the related economic data (with the energy price in Iran)

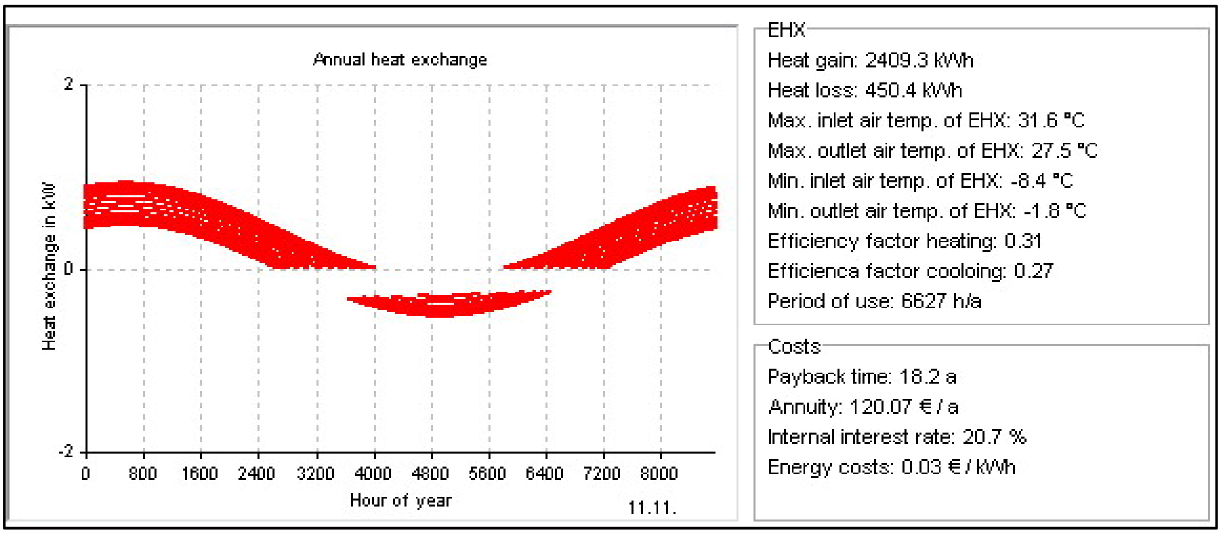


Figure 101: Annual heat exchange in subsoil heat exchanger and related economic data (with the average energy price in other countries)

Based on these figures, the energy saving of such a heat exchanger is

[1] - The characteristics of the building, heat exchanger and the soil where the heat exchanger is placed are as in the following:
Number of pipes: Number of pipes: 4 - Length of pipes: 10.40m - Pipe diameter: 0.20m - Distance between pipes: 3m - Depth of pipes: 4m - Distance from building: 0m - Type of soil: Moist loamy soil - Density: 1800Kg/m³ - Heat Capacity: 1.34KJ/KgK - Thermal conductivity: 1.49W/mK - Ground water level: 10m - Built area: 275.07m² - Building volume: 770.196m³ - Air change rate: 0.5/h.

2409.3kWh in winter and 450.4kWh in summer. Dependent on the built area of the house, this exchanger can save 8.76kWh/m²a heating energy and 1.64kWh/m²a cooling energy. These figures also show that with the energy price in Iran, the use of subsoil heat exchanger is not economically viable because the payback time for investment for a subsoil heat exchanger is more than its utilization time. However; with the average energy price in the other countries, the subsoil exchanger is economically perhaps viable there. With the average energy price in the other countries, the payback time is 18.2 years and the internal interest rate is 20.7%. The cost for generation of 1kWh heat and the coldness with such heat exchanger is 0.03Euro.

The following figures show the temperature of air before entering the subsoil heat exchanger and after outgoing from it in the coldest and warmest days of the year. It shows that if the air enters the heat exchanger in winter when temperature is -8.4°C, the outgoing air temperature will be 1.8°C. In summer, with 31.6°C for the incoming air, the air will be cooled up to 27.4°C when it outgoes.

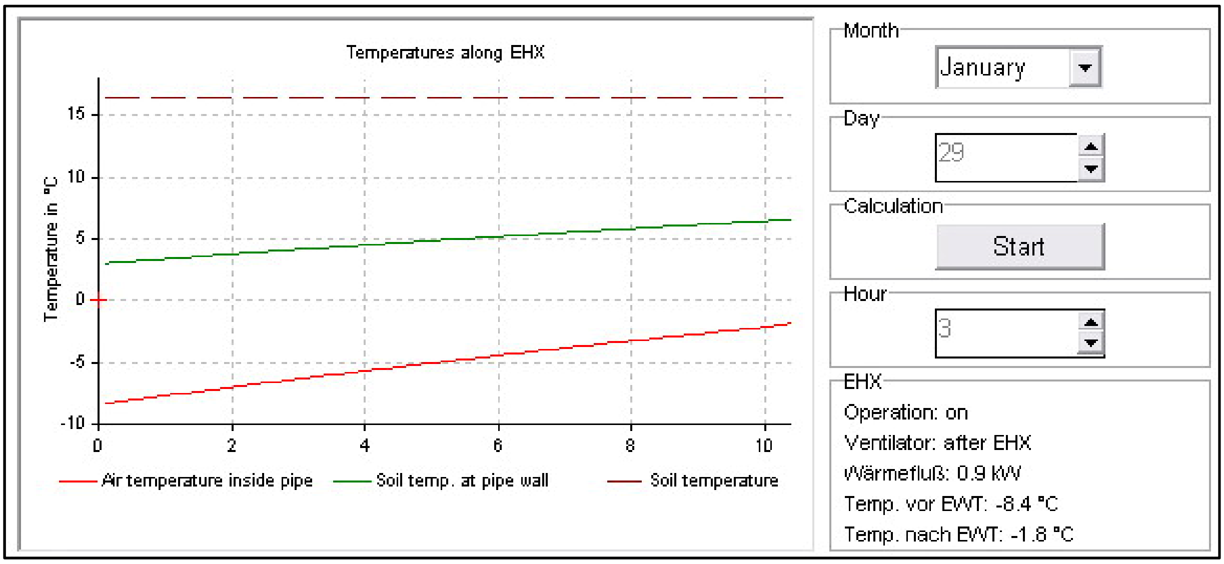


Figure 102: Temperature along the subsoil heat exchanger in 29th of January

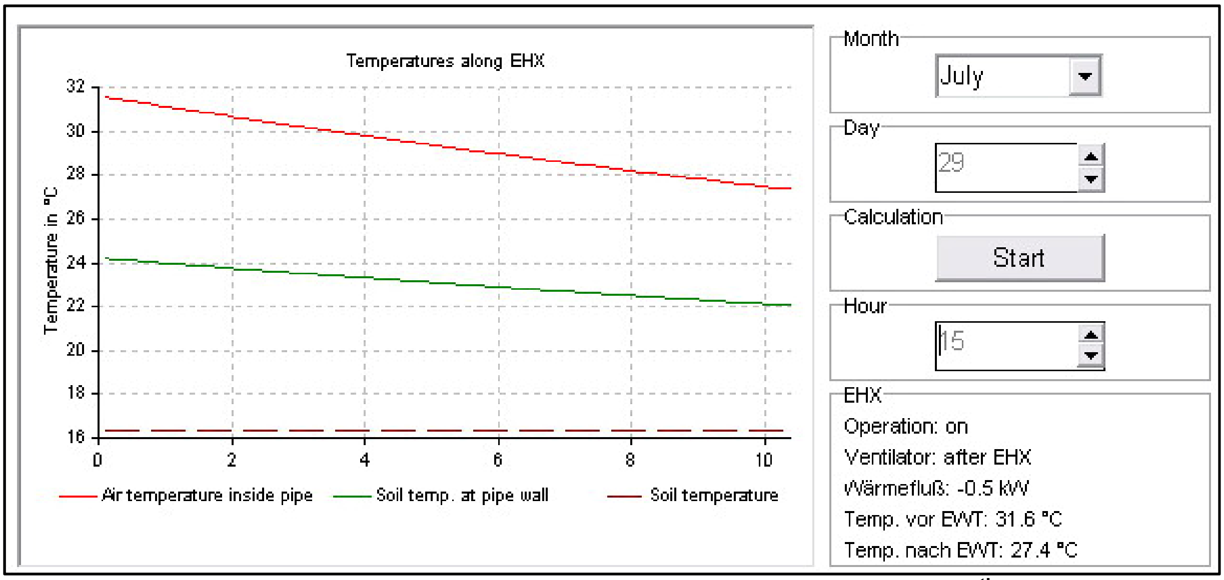


Figure 103: Temperature along the subsoil heat exchanger in 29th of July

Results of Simulations

Simulation of buildings in Tabriz and the analysis of results shows that the following factors reduce the amount of energy consumption of the buildings:

- Orientation of building to south and elongation of building in the east-west axis
- Use of large areas for south-facing windows and small areas for east- and west-facing windows (ideally with the use of fixed vertical shading devices and external movable ones) and very few north-facing windows
- Minimal use of external doors
- Location of uncontrolled spaces and unimportant spaces to the north, east, or west
- Location of living rooms, which are used during the day, to the south
- Use of compact building form which minimises the external envelope
- Use of buildings with more stories (for low rise buildings, three and four level buildings are very effective)
- Location of a part of the building underground (i.e. basement)
- Use of thin (10.5cm) brick walls with solid bricks
- Use of subsoil heat exchanger at the depth of 4m, but not to be used during April, May and June
- Use of equal thickness for wall and roof insulation

Simulation of Architectural Elements

Introduction

Simulation of several buildings has shown that the best case (in terms of energy efficiency) for each building element or architectural factor varies depending on many factors. Among these factors are: climate, building orientation, area of windows and their type, shading devices, compactness, elongation, and building occupancy. Therefore, it is not possible to decide which case is the best for every building component only on the basis of climate and apart from the other factors. Finding the optimal case for one variable of each component is possible only under fixed conditions for all other components and stabling all other variables of the decided component.

This section of the work deals with the interaction between the energy consumption of buildings and architectural factors or building components. It studies the effect of different architectural factors and building elements on energy consumption of buildings and intends to provide conclusions as the most appropriate application for various building components under given, fixed conditions of other components.

Analysis of the simulations provided in the section shows the behaviour of energy efficiency in relation to different measures or quantities of various architectural factors and building elements. It also shows how energy consumption, related to various architectural factors, increases or decreases.

The following graphs are to clarify the behaviour of energy consumption of a building in relation to different architectural factors. As well, they show how the changes in the amount of an architectural element affect the energy consumption of buildings.

Now about 185 buildings are simulated with DesignBuilder, a dynamic developed building energy simulation software tool. The simulated buildings are three stories high, with $100m^2$ substructure. They have no indoor space divisions or rooms. The results are illustrated in numerous graphs, from which many rules regarding various building components can be formulated (the following passages discuss the most important results of the graphs).

This section intends to offer a deep understanding and feeling of the complex behaviour of building energy use in relation to architectural design. The outcomes can be used as a reference for architects and building experts for energy efficient architectural design in the cold climatic region of Iran.

Windows

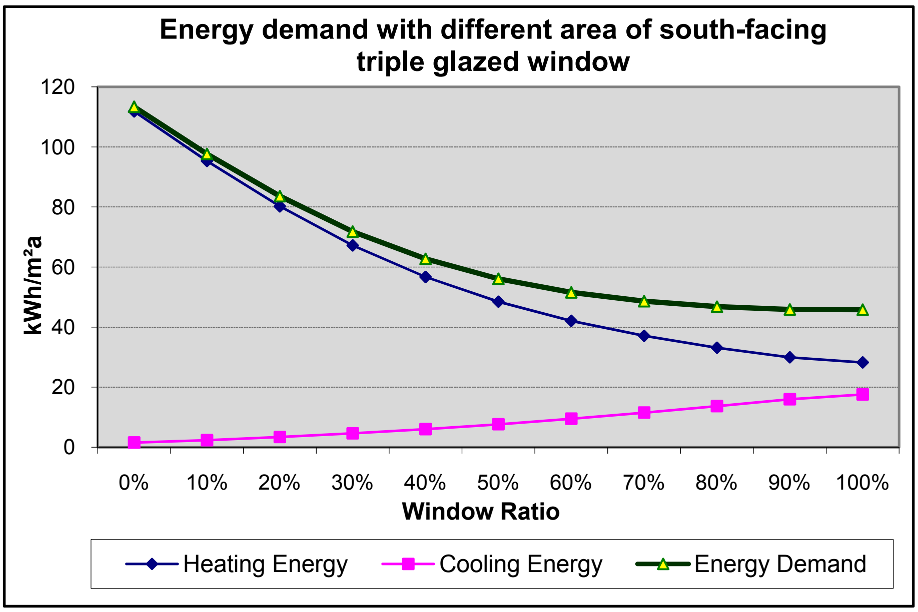
Simulation of several buildings shows that the optimum window ratio both for heating and cooling requirements for each orientation varies with regard to factors such as: climate, building occupancy, the amount of window area in other orientations, type of window (U-factor of glass and window frame, ratio of glass area to window area, solar transmittance), type of shading device and shading device operation, building orientation, ratio of south wall to east wall, etc. Therefore, it is not possible to formulate a rule stating the optimum window ratio for every wall with regards to climate for all buildings.

Different Window Area for a Single Orientation

Triple Glazed Window with External Blind

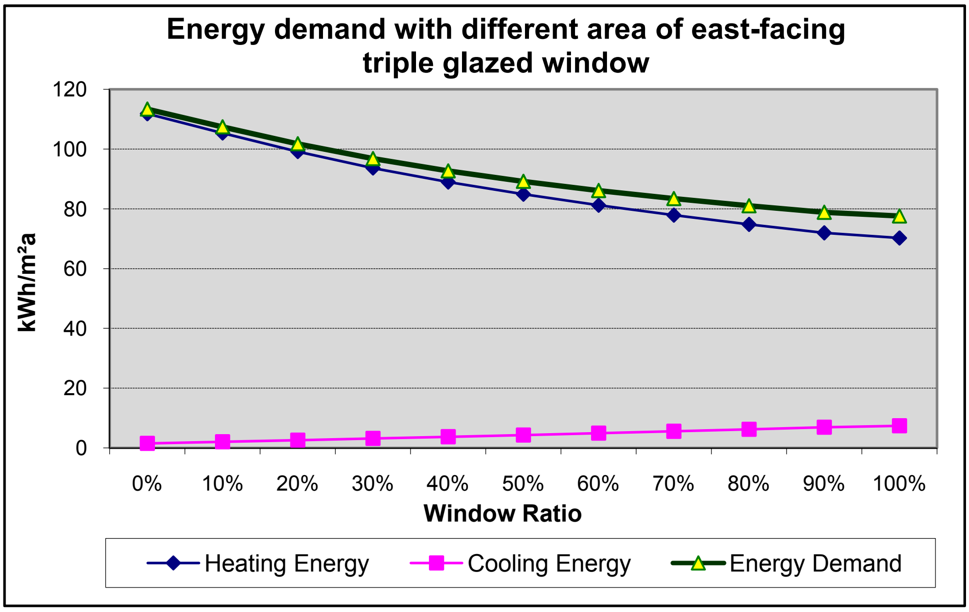
Thirty different three-story buildings with different ratios of triple glazed windows in walls facing south, east, and west are simulated to decide how much window area is the optimum for triple glazed window with external blind to fulfil both heating and cooling requirements. In each case, there is a different ratio of window area on a wall while others have no window. The following graphs show the results of these simulations.

The following graph shows the heating, cooling and total energy demand for buildings with different ratios of south-facing triple glazed windows on one orientation and without windows on the other orientations. This graph shows that increasing the window ratio on the south wall slightly increases the cooling energy demand but significantly decreases the heating energy demand. Increasing the south-facing window ratio up to 100% will effectively decrease the total energy consumption of the building. As a result, if the building has no window on the other wall directions, 100% south-facing window ratio is the optimum ratio for energy efficiency.



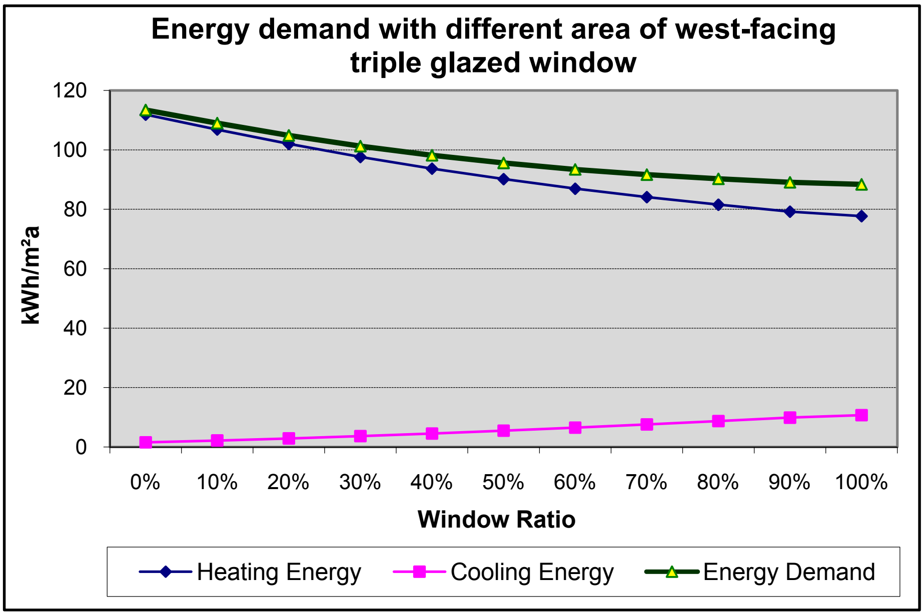
Based on this graph, with a minimal south-facing window ratio, the building has very little cooling energy demand (about zero cooling energy demand with zero window ratio) and high heating energy demand, but with increases in the window ratio the difference between heating and cooling energy demand reduces and with 100% south-facing window the building has almost equal heating and cooling energy consumption.

The following graph presents the energy demands of a building with different ratios of east-facing triple glazed windows and with no window on the other orientations. It demonstrates that increasing the window ratio on eastern walls slightly increases the cooling energy and decreases the heating energy, thus decreasing total energy consumption. Increasing the east-facing window ratio up to 100%, only if there are no windows on the other walls, will decrease the total energy consumption of the building and therefore, under the above mentioned conditions 100% east-facing window ratio is the optimum window proportion for energy efficiency.



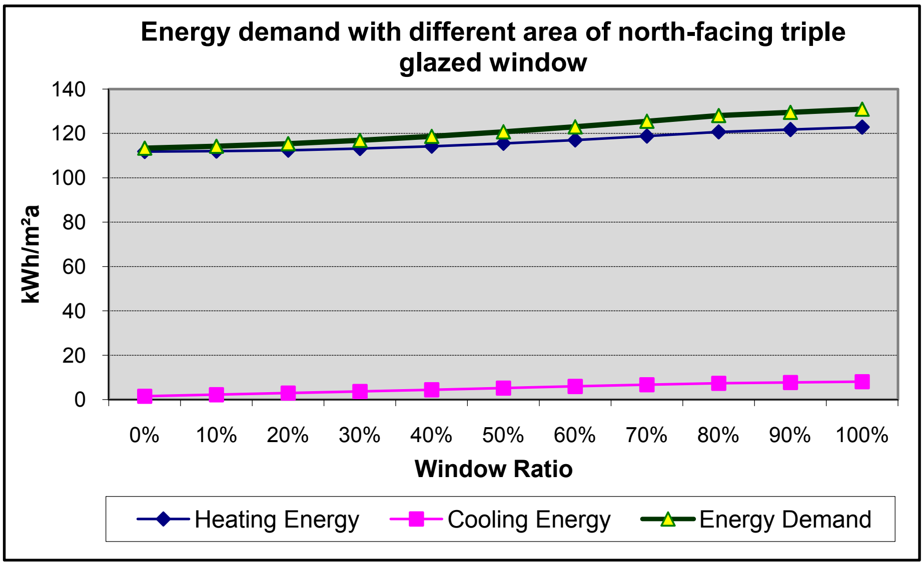
The following graph presents the energy demands of a building with different ratios of west-facing triple glazed windows and with no windows on other orientations. It shows that increasing the window ratio on west-facing walls increases the cooling energy but decreases slightly more the heating energy and thus decreases total energy consumption.

If there are no windows on other walls, increasing the west-facing window ratio up to 100% will decrease total energy consumption of the building and therefore, under these conditions, a 100% west-facing window ratio is the optimum window ratio for reducing a building's energy consumption.



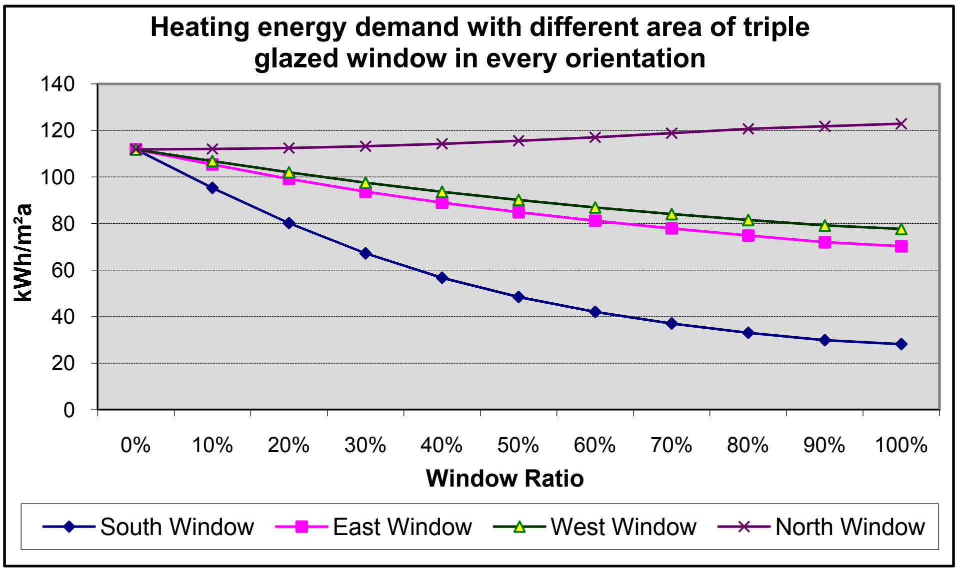
The following graph presents the energy demands of a building with different ratio of north-facing triple glazed windows and with no windows on other orientations. This graph shows that increasing the window ratio on north-facing walls increases both the cooling and heating energy and thus increases the total energy consumption of the building.

North-facing windows receive no direct sunlight in winter but lose some heat. In summer, they gain solar heat and therefore, increase the energy consumption of a building in both winter and summer.

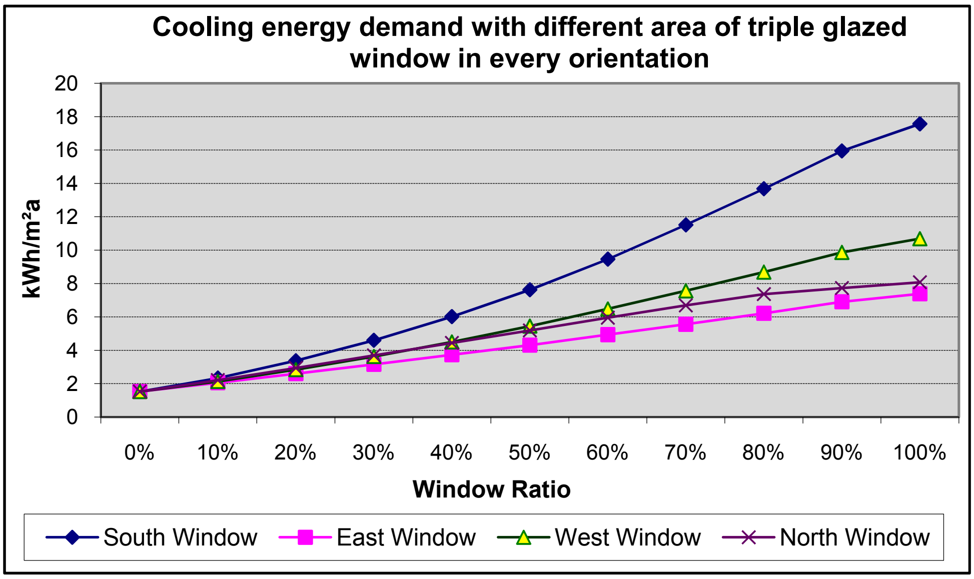


The following graph compares the heating energy demand of a building with different window ratios in every orientation. It shows that increasing the south, east and west-facing windows reduces heating energy demand and increasing north-facing windows increases it.

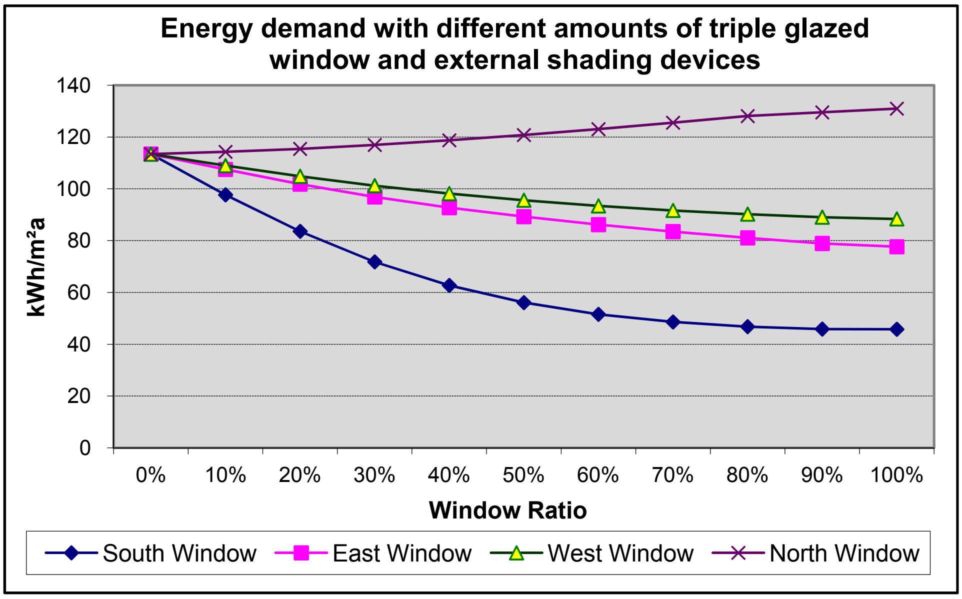
Between all orientations, south-facing windows have the greatest effect on reducing heating energy consumption. East and west-facing windows have almost the same effect on reducing heating energy demand but east-facing windows are slightly more effective.



The following graph compares the cooling energy demand of a building with different window ratios in every orientation. It shows that increasing the window ratio in all orientations increases cooling energy demands of the building. Based on this graph the east, north, west and south-facing windows increase the cooling energy demand. Because the increase in cooling energy demand of the building with windows in all orientations is significantly less than the decrease in heating energy, the total energy consumption of the building must be used for decisions regarding the window ratio.



The following graph compares the total energy consumption of a building with different window ratios in every orientation. It shows that increasing the south, east and west-facing windows reduces energy consumption but by increasing the north-facing windows energy consumption is increased. Among the windows in all orientations, the south-facing ones are the most effective for reducing a building's energy consumption. Thus it is recommended to use the highest possible.



Although east-facing windows reduce the energy consumption much less than south-facing windows, they are more effective than west-facing and also north-facing windows in reducing a building's energy consumption. Use of east-facing windows is recommended more than west-facing windows, because not only do they reduce more energy consumption, but also these windows gain solar heat in the morning, whereas west-facing windows gain it in the afternoon (when the building is often warm and the heat is not needed). Because of the effect of north-facing windows, these windows must be used in buildings as little as possible.

In the case there are triple glazed windows with external shading devices in only one orientation (east, west or south), the greater the window area, the less energy demand of the building. This effect is greater in south-facing windows. Therefore, if a building can only have windows in one of the above mentioned orientations, from the viewpoint of energy, it is better to have a large window area.

Matching Window Ratio at Every Orientation

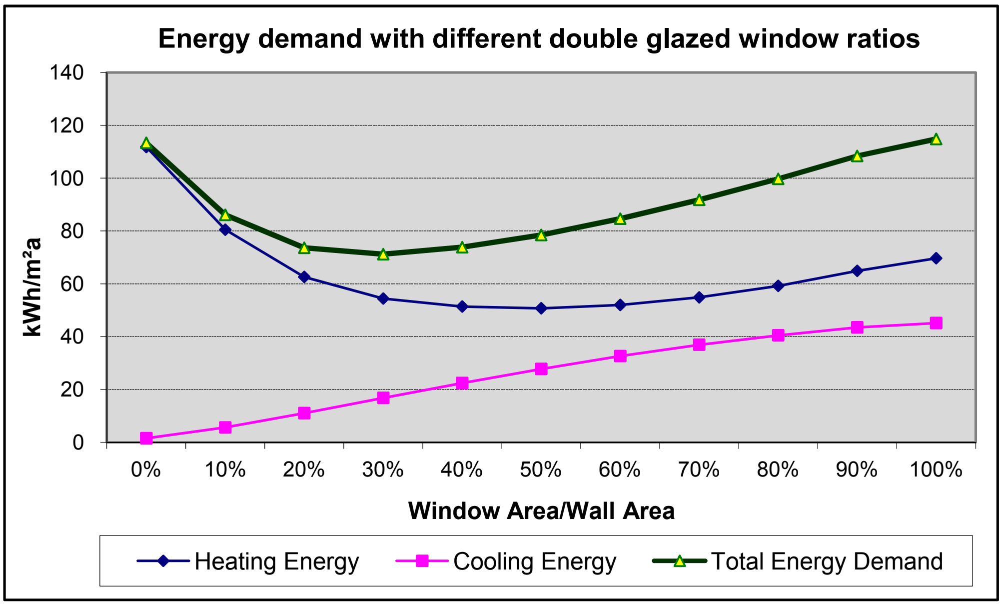
Double Glazed Windows[1] with External Shading Devices[2]

Thirty-three different buildings are simulated to find the best window ratios, when they are the same in all orientations. The results show that increasing the window ratio of all orientations will increase cooling energy demand. However, from 0% to 50%, it will decrease heating energy demand, while from 50% to 100%, it will increase heating energy demand.

[1] - Double Low-E (e3=1) Clear 3mm/ 13mm Argon, Total solar transmission (SHGC) = 0.647, Direct solar transmission= 0.538, Light transmission= 0.769, U-value= 1.514W/m²K.
[2] - Outside blind with medium reflectivity slats, Operation: Day cooling and solar night+ night, Solar set point: 120kW/m².

Increasing window ratio by 0% to 30%, decreases total energy consumption of buildings. But increasing the ratio by 30% to 100%, will increases it.

Therefore, if the building has the same window ratio in all orientations, the best window ratio for heating is 50% and for cooling 0%, and the overall optimum ratio for minimal energy demand is 30% of the wall area being dedicated to windows.



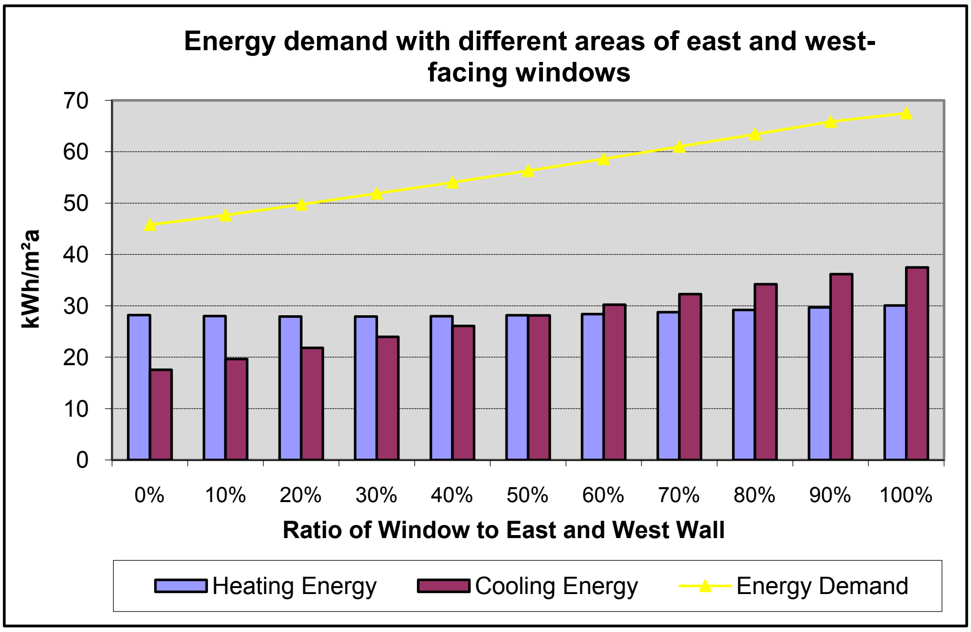
Varying Amounts of East, West and North-Facing Window Areas in Buildings with a 100% South-Facing Window Ratio

East and West-Facing Windows

Results of simulation and analysis show that south-facing windows are very effective in reducing the energy consumption of buildings. Results also show that the ideal situation is 100% south-facing windows with external blinds. Therefore, in order to find the optimum window proportion in different orientations, varying amounts of east, west and north-facing windows are simulated in buildings containing 100% south-facing windows with external blinds.

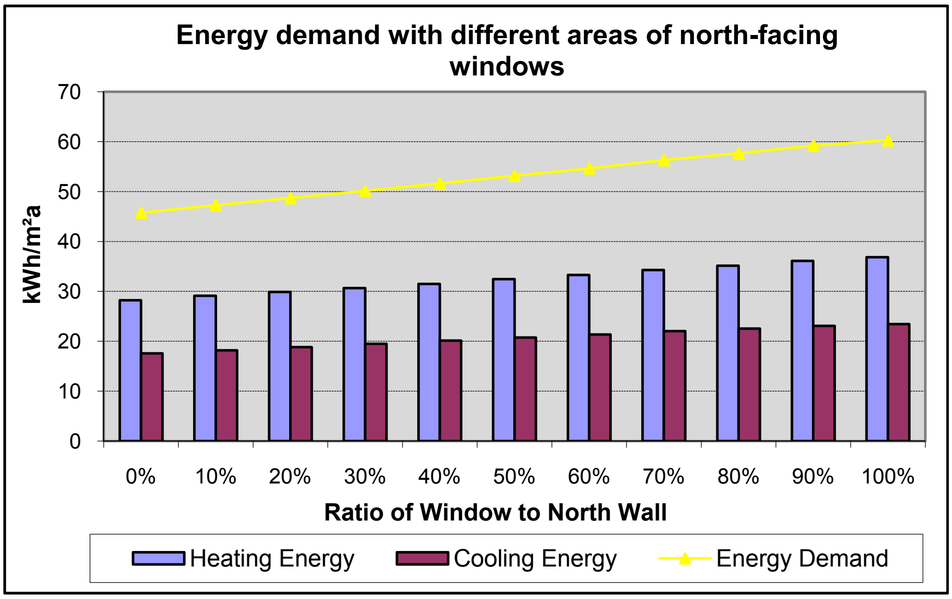
If the building has 100% south-facing (and no north-facing) windows, increasing the east- and west-facing windows has minimal effect on the heating energy demand. Having up to 30% east- and west-facing windows reduces heating energy demand by very little, and by increasing window surface area to 100%, heating energy demand will be increased. Increasing east- and west-facing windows from 0% up to 100% effectively increases the cooling energy required and thus the total energy demand.

Because the energy consumption of buildings increases as east- and west-facing windows increase, these windows must be used as little as possible, if the building is able to have sufficient south-facing windows.



North-Facing Windows

If the building has 100% south-facing and no east- and west-facing windows, increasing the ratio of north-facing windows increases both heating and cooling energy required and thus the total energy demand. Therefore, north-facing windows must avoided or minimised.



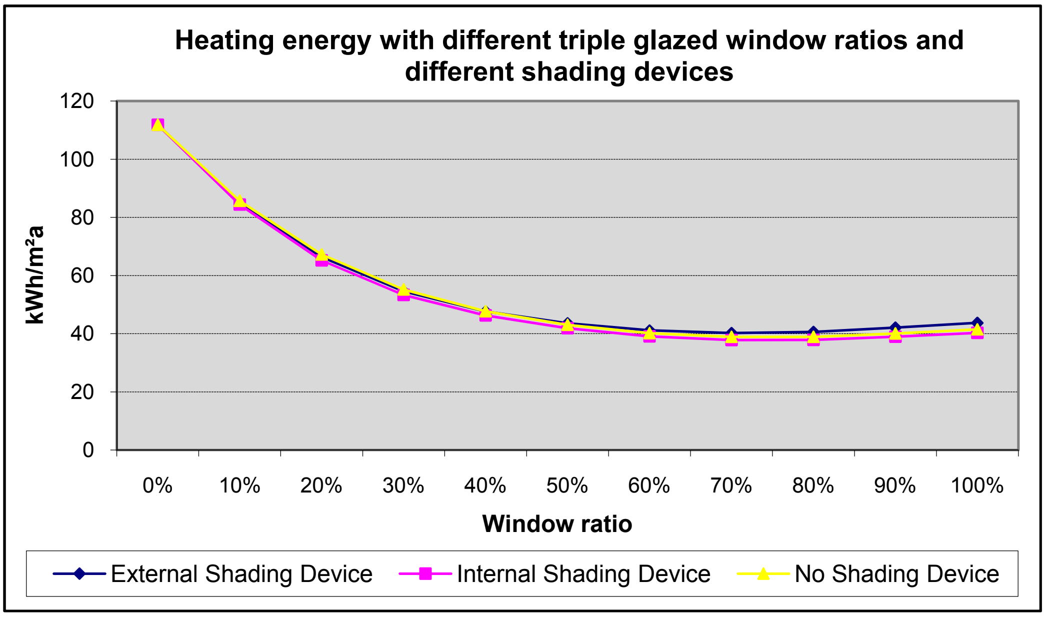
Shading Devices

Effect of Shading Devices on Energy Demand in Triple Glazed Windows[1] with Same Window Ratio in Different Orientations

Thirty-three different buildings with different ratios of triple glazed windows in all walls (south, east, west and north-facing walls) are simulated with and without external[2] and internal[3] shading devices to show the effect of various shading devices on triple glazed windows, when all walls have the same ratio of window area. The following diagram compares the heating energy demand of a building by altering window ratios and shading devices.

The following graph shows that under the mentioned conditions, shading devices (that are controlled based on heating and cooling energy requirements) have a minimal effect on the heating energy consumption of buildings. With variations in window area, the buildings with external shading devices have slightly more heating energy demand than buildings with no shading devices. They also demand heating energy slightly more than the buildings with internal shading devices.

The optimum window ratio in all orientations, regarding heating alone, and including internal, external, and no shading devices is 70%.



The following diagram compares the cooling energy demand of a building with different window ratios and different shading devices. This graph shows that if the building has the same triple glazed window ratio in all orientations, the

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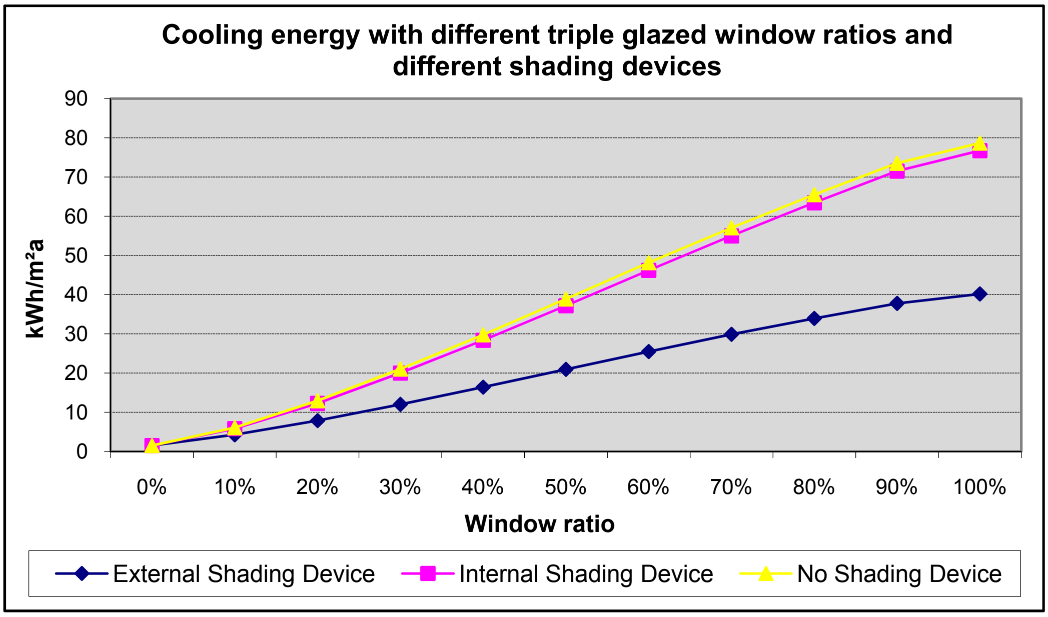
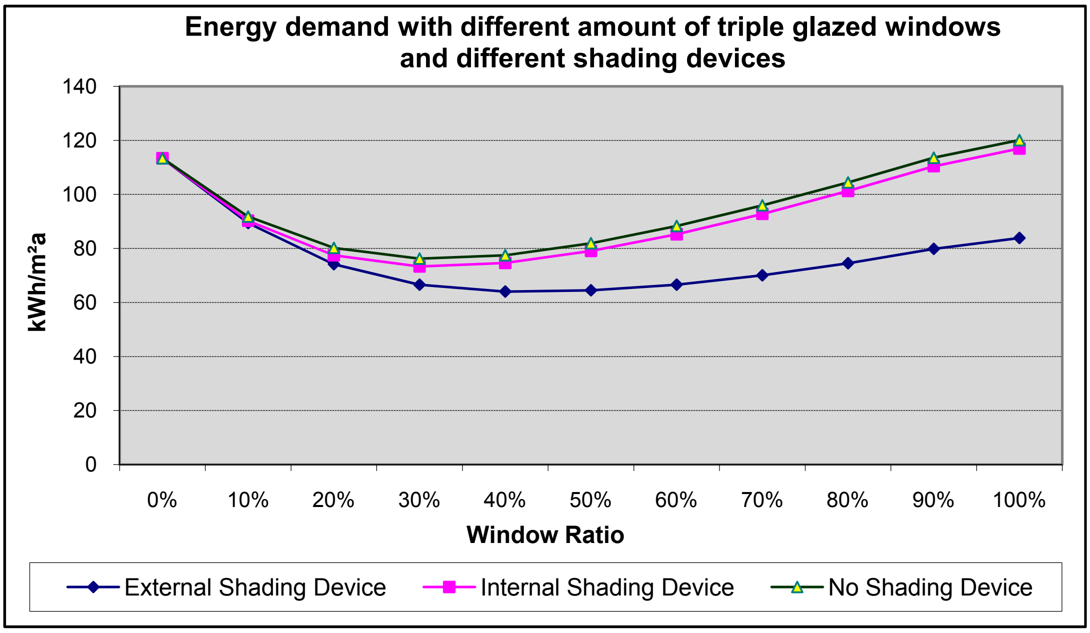
[1] - Triple Low-E (e2=e5=1) Clear 3mm/ 13mm Argon, Total solar transmission (SHGC) = 0.470, Direct solar transmission= 0.358, Light transmission= 0.661, U-value= 0.786 W/m²K.
[2] - Outside blind with medium reflectivity slats, Operation: Day cooling and solar night+ night, Solar set point: 120kW/m².
[3] - Inside blind with medium reflectivity slats, Operation: Day cooling and solar night+ night, Solar set point: 120kW/m².

type of shading devices have a significant effect on cooling energy consumption of the building. With variations in window area, a building which uses external shading devices has a significantly smaller cooling energy demand than a building with internal shading devices and also with one with no shading devices. However, the building with internal shading devices has only a little less cooling energy demand than the building with no shading device. This shows that for solar control in summer, the internal shading devices have a very small effect on reducing the cooling demand.

The optimum window ratio for cooling only with internal, external, and no shading devices is 0% because the glass surfaces of buildings gain solar heat in summer and thus increase cooling demand.



The following graph compares the total energy consumption of a building with different amounts of window ratio and with different kinds of shading devices.



This graph shows that interior shading devices for windows of different orientations have minimal effect on the total energy consumption of buildings. Consequently, they provide only small reductions in the building's energy needs.

External shading devices for windows of different orientations have a great effect on the building's energy consumption and effectively reduce it with the use of varying amounts of window area. Increasing the amount of window area will increase the ability of external shading devices to reduce the energy consumption in comparison to internal shading devices or no shading devices.

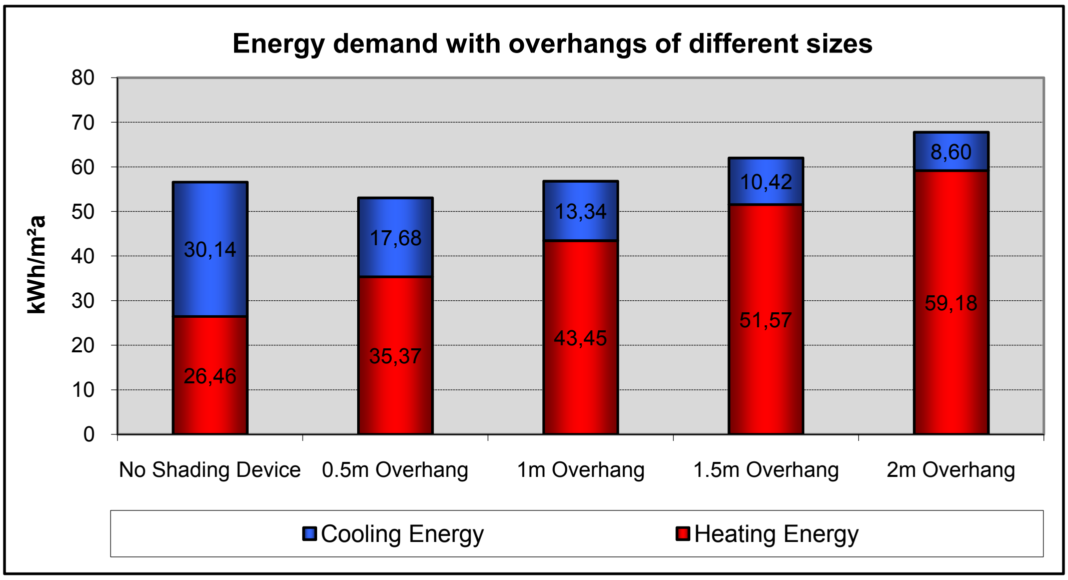
With varying window ratios, external shading devices are much more effective than internal shading devices. Internal shading devices, however, are a little better at reducing energy demand than no shading devices.

With external shading devices, the optimal window ratio (in all orientations) is 40% but with internal shading devices, and with no shading devices, the most efficient window ratio is 30%.

Effect of the Size of External Shading Devices on Energy Demand

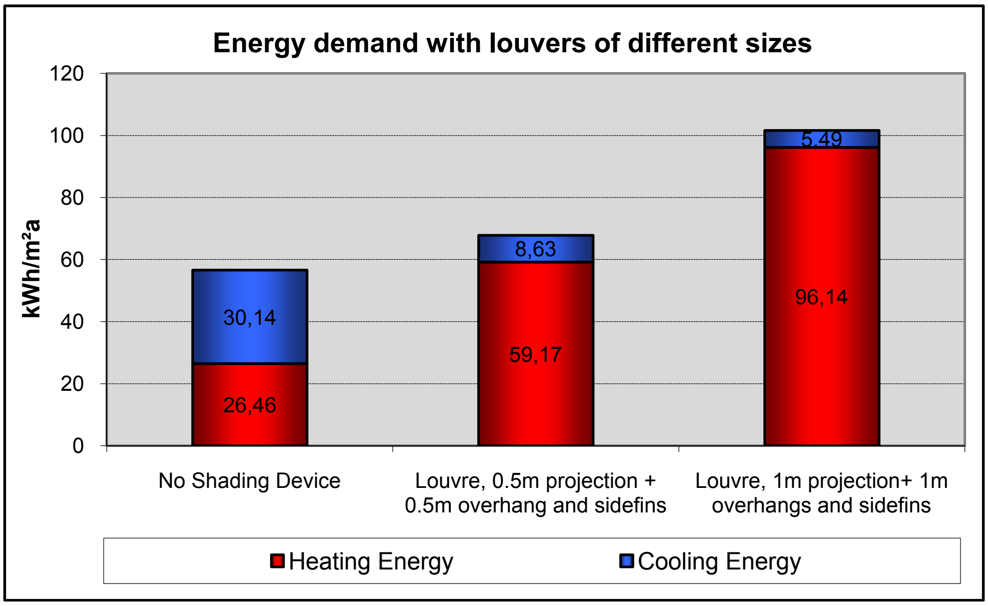
To estimate the effect of the size of different external shading devices on a building's energy demand, buildings with different types and sizes of shading devices are simulated. The building has a 100% triple glazed south-facing window ratio and no windows on the other walls. The height of windows in this building is 2.86m.

The following graph compares the energy demand of a building with overhangs of different sizes and the same building without shading devices on the south-facing windows. It shows that having 0.5m overhangs for south-facing windows reduces the energy consumption but increasing the size of overhangs will increase the building's energy consumption.

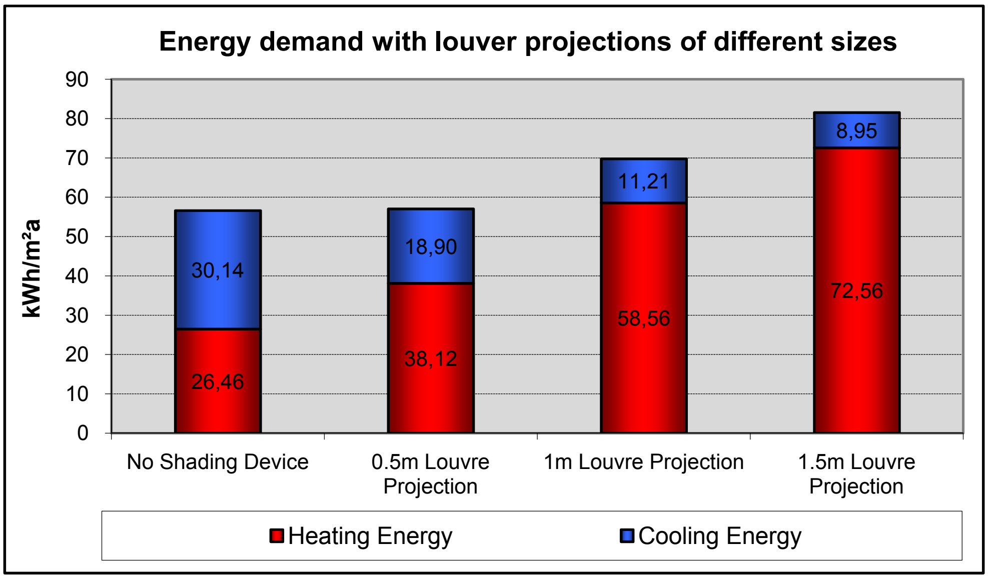


The following graph compares the energy demand of a same building when it has no shading devices with when it has louvres of different sizes. It shows that the building without shading devices demands less energy than the building with louvres on the south-facing windows. Increasing the size of louvres also increases the building's energy consumption.

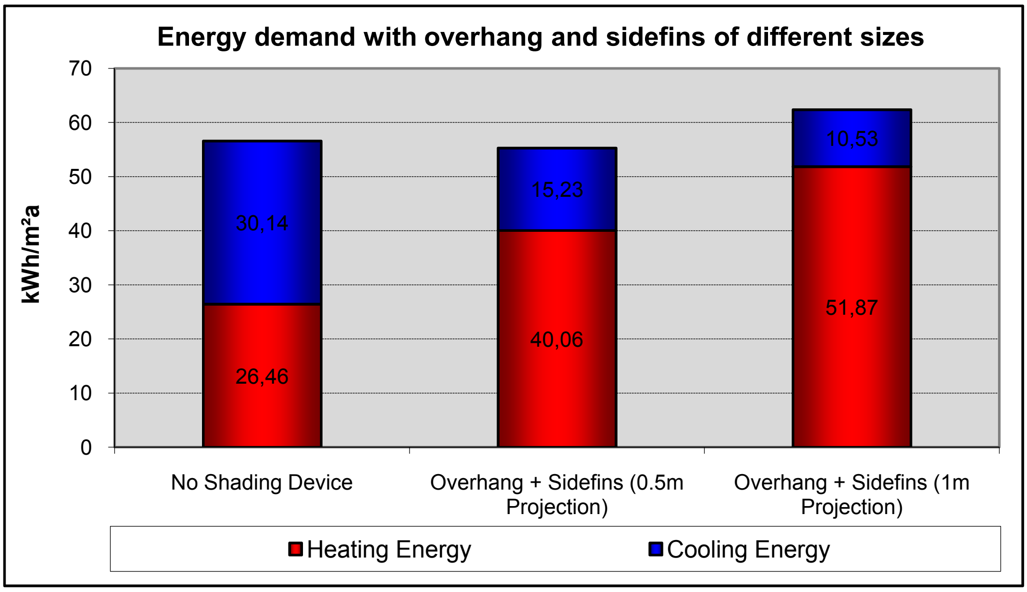
This is because louvres on south-facing windows increase heating energy demand more than they reduce cooling energy demand. South-facing windows receive much more solar energy for heating the building and therefore, southern louvres limit the solar gains in winter. Minimising winter solar gain with unsuitable shading devices will increase heating and total energy demand.



The following graph compares the energy demand of a building with different length louver projections (0.5m, 1m, 1.5m) and without shading devices. It shows that the building without shading devices has a little less energy consumption than the building with louver projections. Although increasing the size of louver projections reduces cooling energy it increases heating energy much more and thus increases the building's energy consumption.



The following graph compares the energy demand of a building with overhangs, without shading devices, and with side fins of different sizes. It shows that having 0.5m overhang and side fins reduces the energy consumption but increasing the size of such shading devices will increase the building's energy consumption.



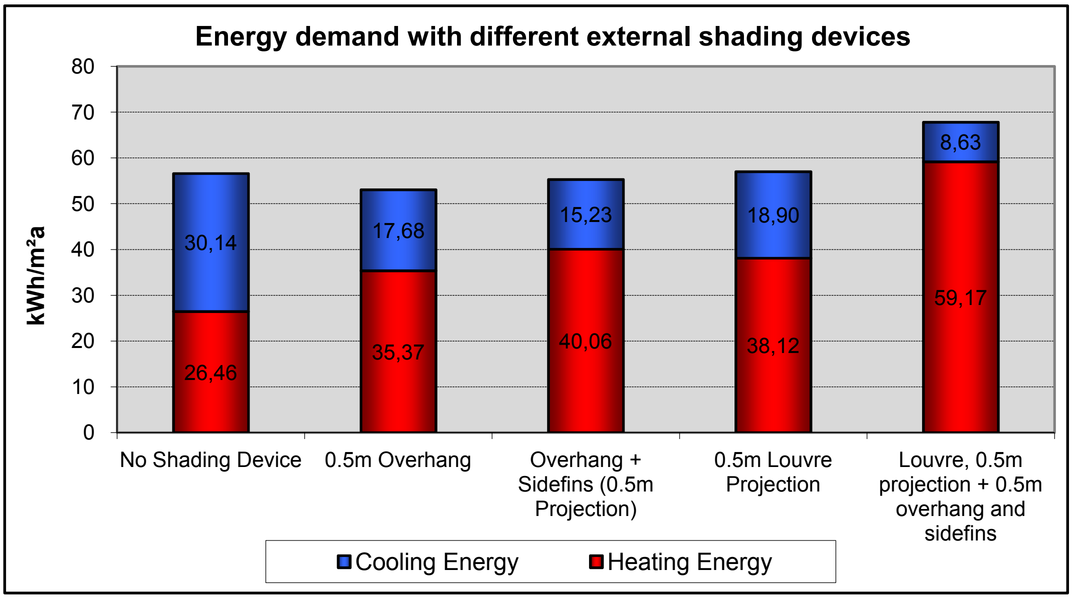
Shading devices generally reduce cooling energy and increase heating energy demand. Increasing the size of shading devices will increase this effect. The reduction in cooling energy and increase in heating energy is related to the climate and window orientation. With some types of shading devices used on south-facing windows the increase in heating energy is more than the decrease in cooling energy and thus, these shading devices increase total energy consumption.

With some types of shading devices, the cooling demand decrease is more than the heating demand increase only up to a particular size of shading device and after this size, the heating demand increase is more than cooling energy decrease thus having a negative effect on the building's energy consumption. Therefore, for optimum energy consumption, the type and size of shading devices in every climate, as well as window orientation must be designed with consideration of the window dimensions and building function.

Comparison of Different External Shading Devices

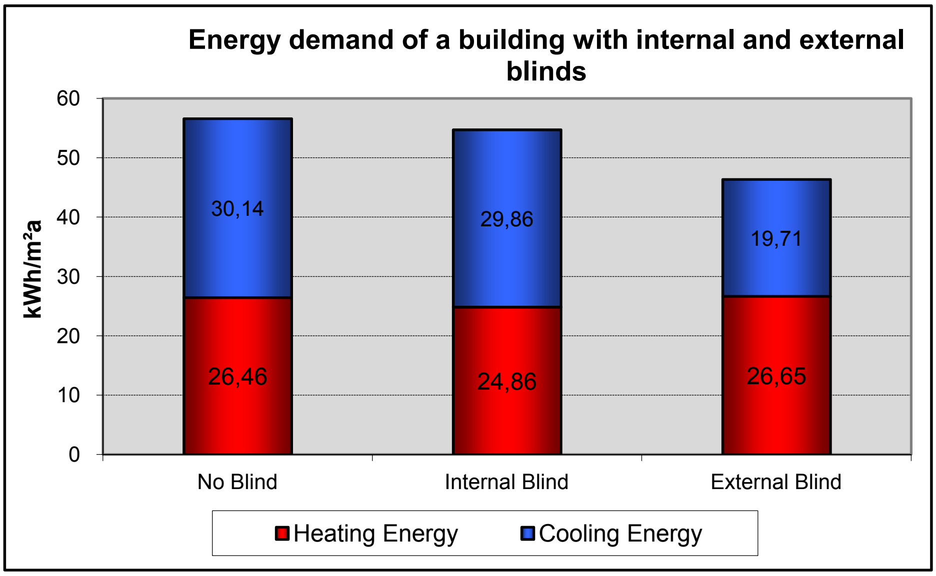
The following graph compares the heating and cooling energy consumption of a building with different types of external shading devices such as "overhangs", "overhangs + side fins", "louver projections" and "louver projections, overhangs and side fins". The building has a 100% triple glazed south-facing window ratio and no windows on the other walls.

Comparison of different external shading devices of the same size shows that, for south-facing windows, overhangs have the best effect on the energy demand of buildings.



Comparison of Internal and External Blinds

The following graph compares a building without any shading devices and with internal and external blinds with the same type of operation (Day cooling and solar + Night). This graph shows that having blinds reduces the amount of energy consumption and, although external blinds increase the heating energy demand of the building more than internal blinds, they have a greater reduction on the cooling energy needed and thus reduce total energy consumption of the building. Therefore, having external blinds reduces the building's energy demand in comparison to having no blinds or internal blinds.



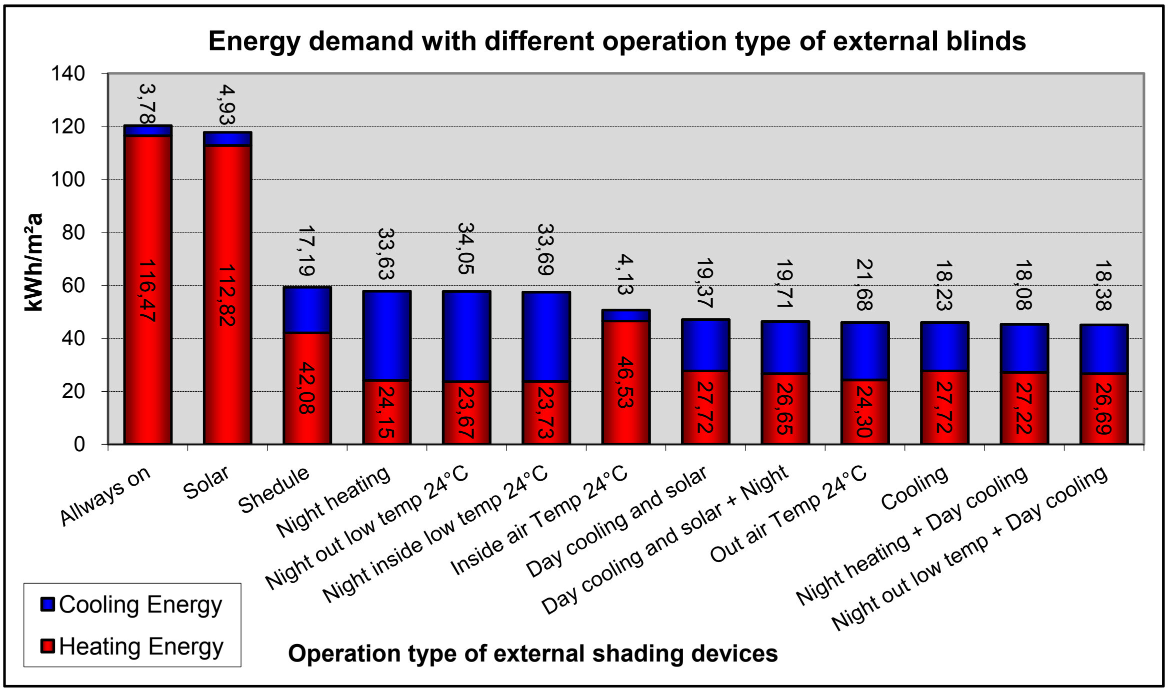
Operation Type of Shading Devices (External Blinds)

Movable, adjustable, and removable shading devices must be operated with respect to heating and cooling needs for different times of the year, seasons, and days. Operation type has a significant effect on heat gain and heat loss of glass surfaces and thus on the heating and cooling energy demands of buildings. It therefore affects the energy consumption of buildings.

In this section, a residential building with external blinds is simulated with variations in blind operation. The following diagram compares the heating, cooling and total energy demand of this building with different operation types. Major differences between the energy demand of these buildings show that the operation of movable shading devices (especially external shading devices) has a significant effect on the energy demand of the buildings, and the efficiency of the blinds.

This diagram shows that:

- When external blinds are constantly on, they reduce the cooling energy demand by blocking solar radiation from the window surface; however, it increases the heating energy demand much more and thus effectively increases the total energy demand of building.
- Operation of shading devices with respect to "Night out low air temperature + Day cooling" has the best effect on the energy demand of a building.
- The type of operation is different with respect to orientation, window ratio, etc.

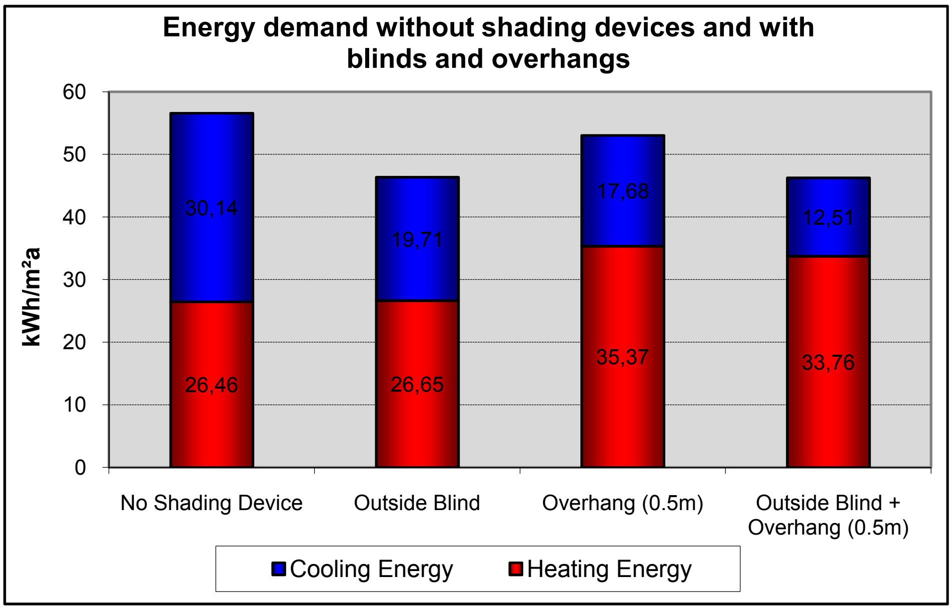


Effect of External Blinds and Overhangs

The following graph compares the energy demand of a building without shading devices, with external blinds, overhangs, and both blinds and overhangs. The building has a 100% triple glazed south-facing window ratio and no windows on the other walls.

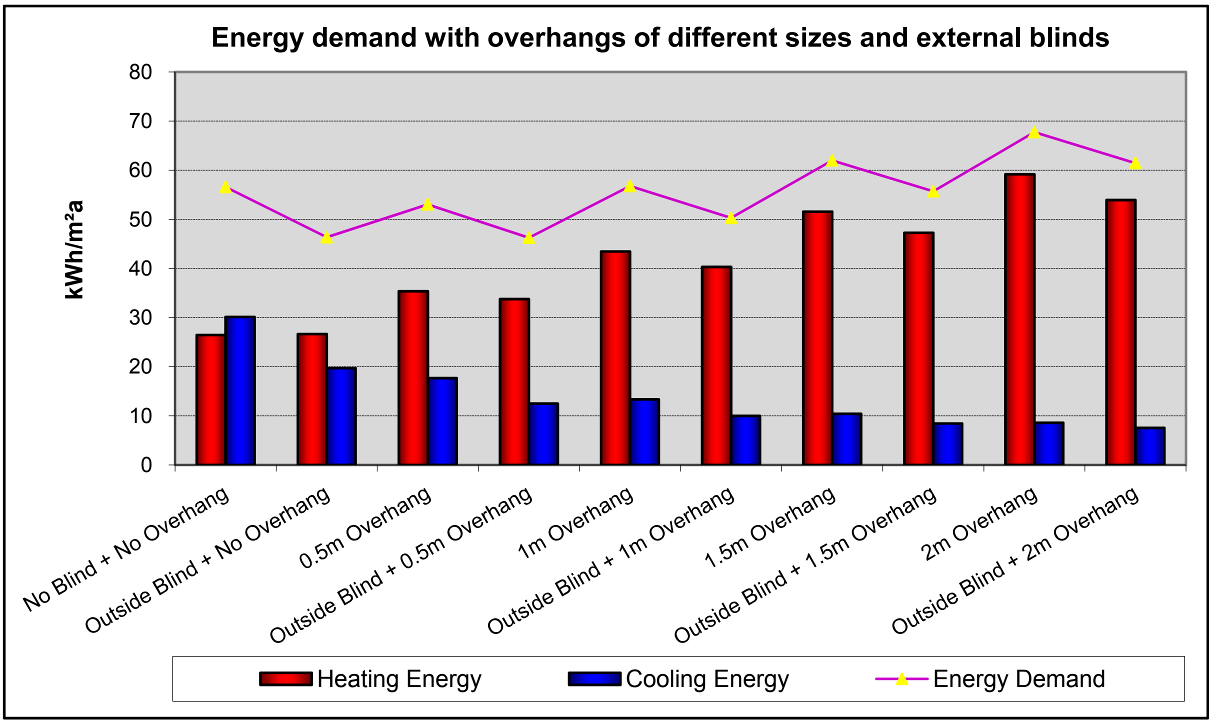
The building with shading devices has less energy demand than the building without shading devices. The building with overhangs has a greater energy demand than the building with external blinds because, not only do external blinds prevent solar radiation from entering the building (like an overhang) but they are also more controllable and thus can be opened when solar heating is needed and closed when it is not needed.

The building with both external blinds and overhangs requires a little less energy than the building with only external blinds. Therefore, for more accurate results, the energy consumption of this building with external blinds and different overhang sizes must be compared.



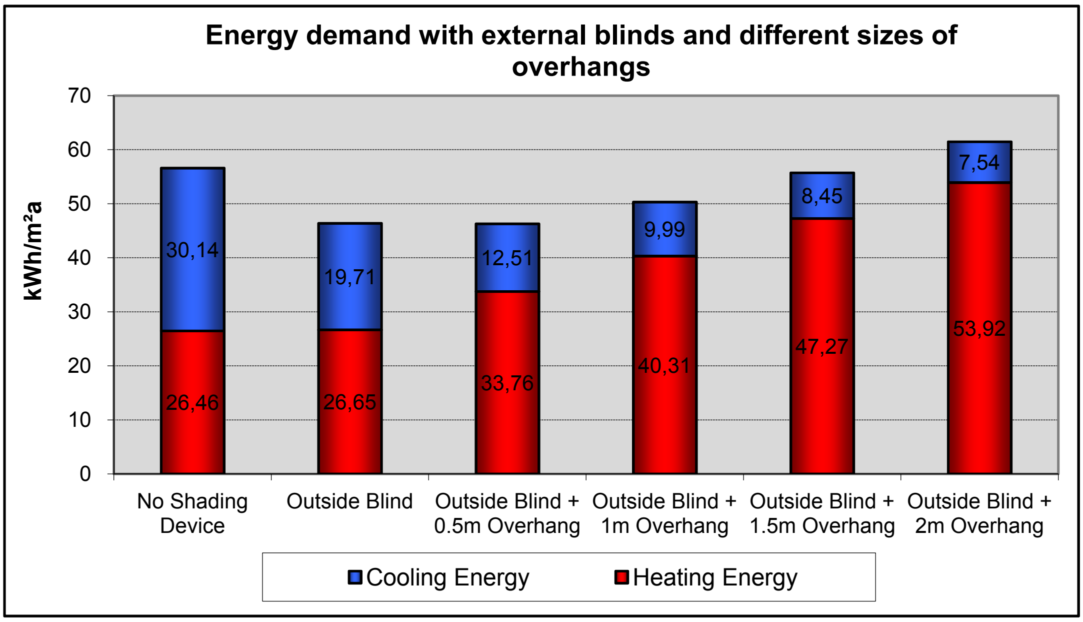
Effect of Overhang Size on Buildings with External Blinds

The following graph compares the energy consumption of a building with external blinds and overhangs of different sizes.



With varying overhang sizes, the building with both overhangs and external blinds, requires less energy than the building with the overhang alone. This means that using both external blinds and overhangs is better than using only overhangs. It also shows that out of all the configurations, the use of just external blinds, and also external blinds with a 0.5m overhang, have the best effect on energy saving in buildings.

The following graph compares the energy consumption of a building with blinds and overhangs of different sizes. Increasing the size of overhang will slightly reduce the cooling energy needed but more significantly increase the heating energy and thus increase total energy needs. Long overhangs will reduce the solar heat gain, even in winter, and have a small effect on required cooling energy because in these buildings the solar radiation is controlled with external blinds.



Use of 0.5m overhang in the building with external blinds slightly reduces the total energy demand. It increases heating energy and decreases cooling energy. Cooling the buildings is more difficult and more expensive than heating the buildings, especially in regions with enough solar radiation. Therefore, because the building with external blinds and 0.5m overhang has a little less total energy consumption than the building with only external blinds and considerably less cooling energy demand, it is recommended to use the external blind with 0.5m overhang. Use of external blind with 0.5m overhang has the advantage that if the users do not control the external blind, overhang has its effect without relying on occupant behaviour.

Result of Shading Devices

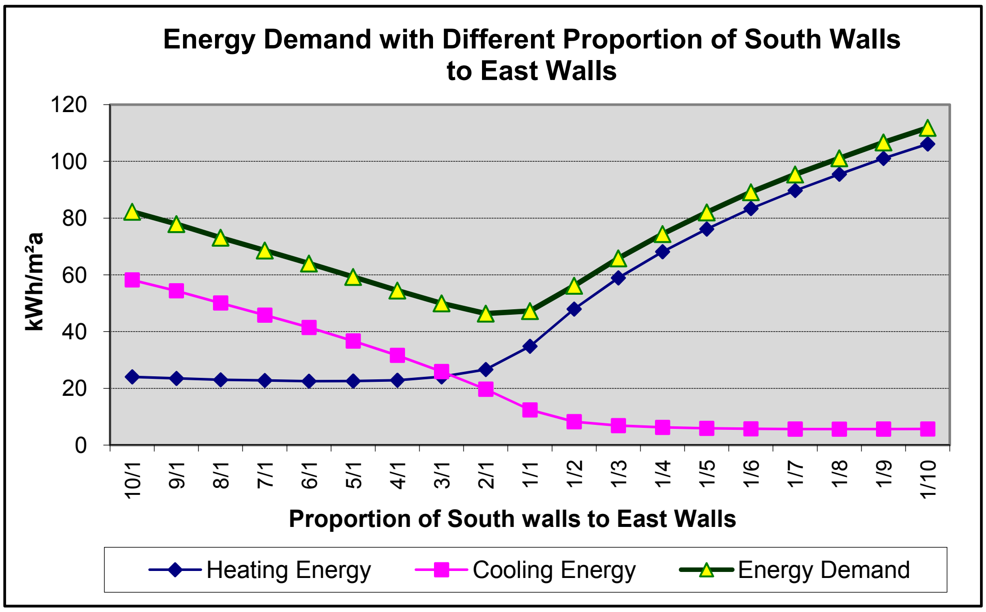
Based on the results of the simulation, outside adjustable and movable shading devices (especially external blinds) have more effect on energy consumption of the building. They reduce both cooling and heating energy consumption of buildings in comparison with fixed shading devices, because they are adjustable according to need. Adjustable and movable shading devices only have the above mentioned effect if they are correctly controlled.

Of all the shading devices, external blinds have the best effect on a building's energy consumption, especially when it is controlled with respect to "Night out low air temperature + Day cooling". To have this effect, they must be correctly and accurately controlled by users or must be controlled automatically. The colour and the reflectivity of external blinds also affect their efficiency.

The type and size of different external fixed and adjustable shading devices has a significant effect on the building's energy consumption and must be designed with attention to climate, window orientation, building function, and so on.

Elongation

Nineteen different buildings (with 100% south-facing windows[1]) with different proportions of south-facing wall to east-facing wall are simulated. These proportions range from 1/10 to 10/1. These simulations show that increasing the proportion of southern walls to eastern walls generally decreases the heating energy demand and increases the cooling energy demand but with the proportion of 6/1 the building has the least heating energy demand and with 1/8 the least cooling energy demand. The building also has the least total energy demand, if the south-facing wall is double the surface area of the east-facing wall.



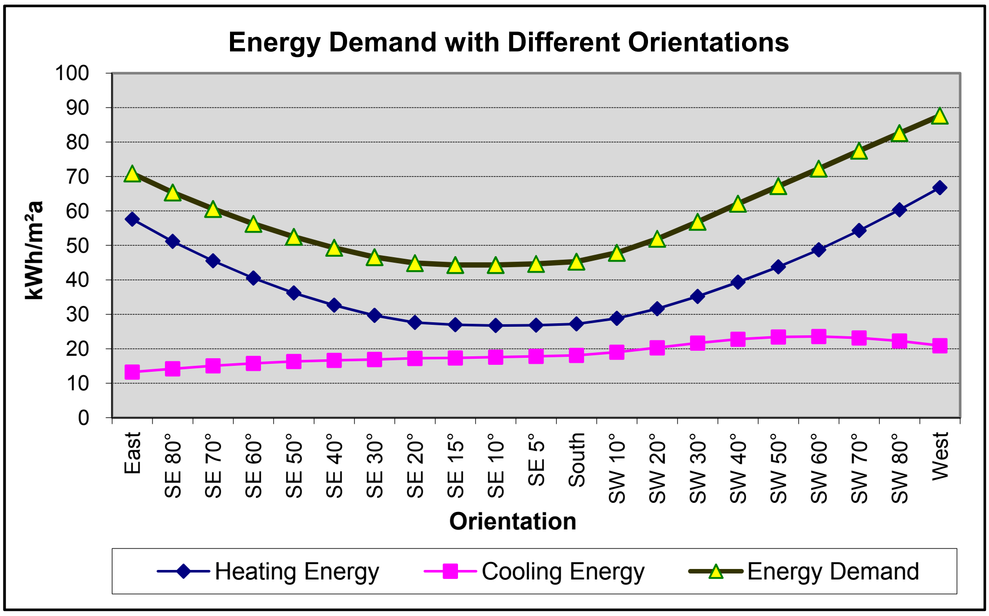
The total energy consumption of a building with equal south and east-facing walls is a little more than the building in which the south-facing wall is double the east-facing wall, but this building requires much less cooling energy. Because cooling of a building is more difficult and more expensive than heating, the optimum ratio of south to east-facing walls is 1/1 (and it can be increased to 2/1).

[1] - The windows are triple glazed windows and have external blinds.

On the other hand, if the site area has east-west elongation, the depth of the south courtyard and the distance between neighbouring buildings in a south-north axis is less[1] and produces shading of the buildings behind (neighbouring buildings) and effectively increases the heating energy consumption of the shaded buildings.

Orientation

Twenty-four similar buildings with different orientations are simulated to find the best orientation for minimising energy consumption. These buildings have 100% south-facing triple glazed windows[2] with external blinds[3] and no window area for the other orientations. The south-facing wall in these buildings is twice as long as the east-facing wall. These buildings have these conditions because the last simulations have shown that they have the best effect on energy consumption. These different orientations start from east and finish at west, with a 10 degree difference between each (and 5 degrees either side of the best orientation).



The results of these simulations show that rotating the building from east to south and west will increase the cooling energy demand and thus the building with east orientation demands the least cooling energy in comparison with those with other orientations. But the difference between the cooling energy demands is only minor and has less effect on the total energy demand in comparison with

[1] - According to Iranian Building Codes and Standards, the depth of courtyard is a given proportion (0.67) of the depth of the building and thus increasing the east-west elongation of a building in a given site area, decreases the depth of the courtyard.

[2] - Triple Low-E (e2=e5=1) Clear 3mm/ 13mm Argon, Total solar transmission (SHGC) = 0.470, Direct solar transmission= 0.358, Light transmission= 0.661, U-value= 0.786 W/m²K.

[3] - Outside blinds with medium reflectivity slats, Operation: Night heating + Day cooling, Solar set point: 120kW/m².

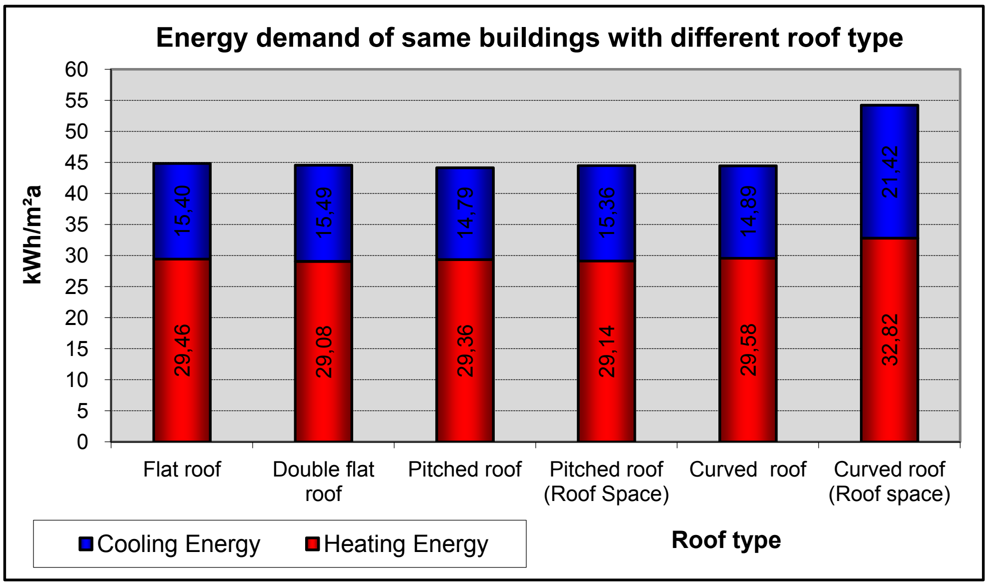
the heating energy demand. Rotating the building from south to east or west will increase the heating energy demand and thus the total energy demand.

Based on the graph above, the optimum orientation for having minimal total energy demand is 10 degrees east of south.

Roof

To find the most suitable roof type (from the viewpoint of energy efficiency), some of the same buildings with different roof types are simulated. These simulations show that between flat, pitched and curved roofs (with roof space), flat roof building has less energy demand in comparison with the other two.

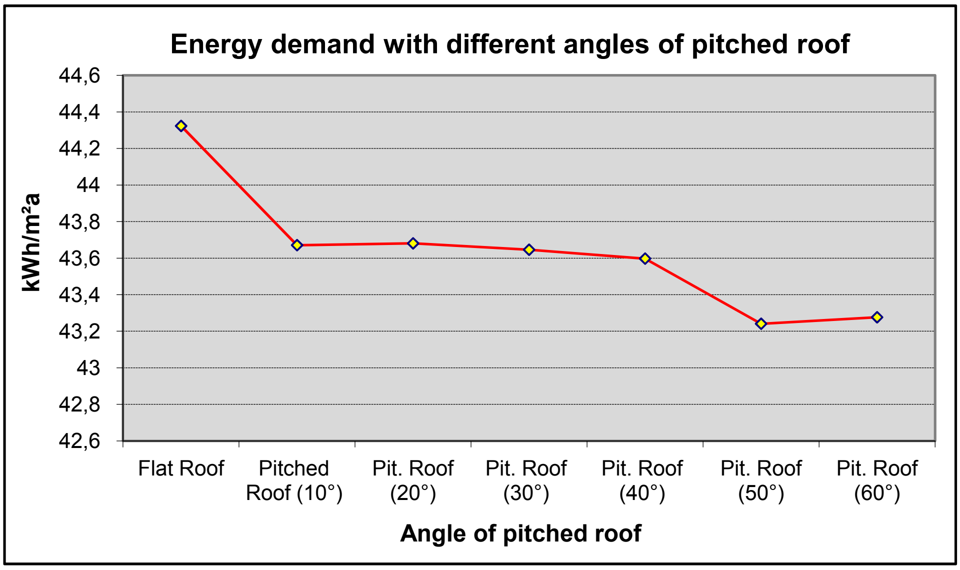
If there is a pitched roof over the flat roof without residential roof space, the building has a slightly smaller energy demand in comparison with a flat roof. But this difference is so little (1.5%) that the building of another pitched roof over the flat roof (for energy reasons alone) is not economically recommended.



Roof Pitch

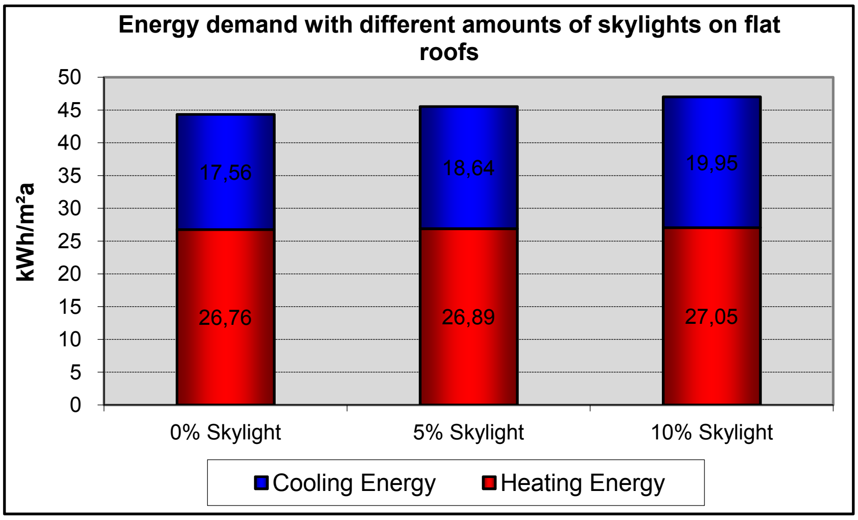
In order to find the effect of a pitched roof construction over the flat roof, and also the effect of the degree of tilt of this pitched roof on a building's energy consumption, seven different buildings with flat roofs and pitched roofs of different angles are simulated and compared in the following graph.

The simulations done to find the effect of constructing of a pitched roof over the flat roof (without residential roof space) and the effect of the angle of the pitched roof shows that constructing a pitched roof over a flat roof reduces the energy consumption of a building. It also proves that 50° (from horizon) is the ideal roof pitch. But in this case, the building has only 2.4% less energy demand than the same building with a flat roof. Therefore, if the space between pitched and flat roof is not used for a special heating or cooling reason, it is recommended to use flat roofs due to economic reasons.



Skylights on Flat Roofs

This simulation shows that the use of skylights on flat roofs increases heating, cooling, and total energy demand. Therefore, the use of skylights in flat roofs is not recommended.



Simulation of Buildings with Different Architectural Designs

Introduction

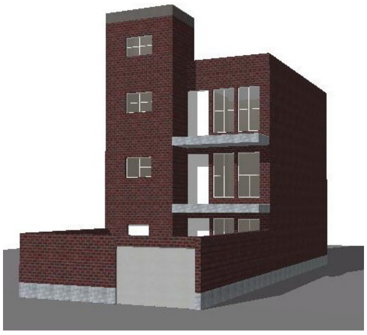
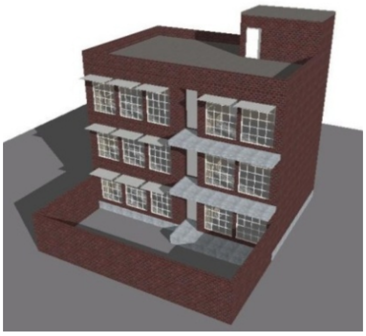
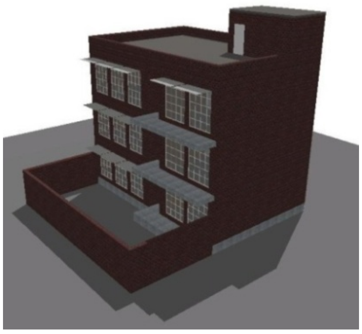
To estimate the effect of architectural design on energy consumption of buildings in Tabriz, an average existing 3-story building[1] in Tabriz is selected and its heating and cooling energy demand is calculated through energy modelling. The building is then simulated with an insulated thermal envelope. Finally, other buildings under the same conditions but with different architectural design characteristics are designed and simulated. In every case, the new building is designed so that it is similar to the previous building with only in one variation. Then, in order to neutralise the effect of control variables on the results, similar buildings differing only in one factor are compared with each other. Therefore, the change in energy demand is affected only by the different factor.

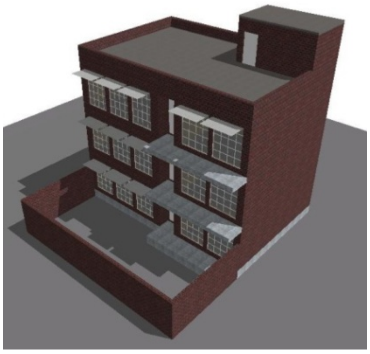
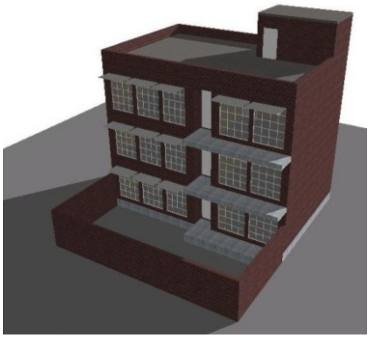
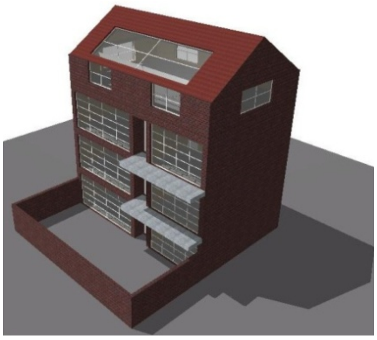
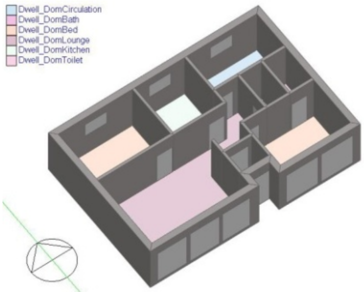
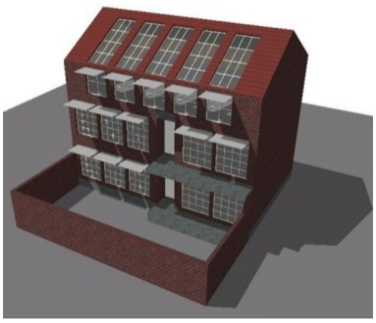
In this section of the research (simulation and analysis), both heating and cooling energy demands of buildings are calculated and the results address reduction of both heating and cooling energy consumption. Most of the analysis and conclusions use total energy consumption. Heating and cooling energy consumption are rarely used separately for analysis.

The following tables present these buildings, their characteristics, their heating and cooling energy demand, and two different perspectives, showing the shading and sun radiation at walls and especially windows during winter and summer.

1 - The built area of an existing and all newly designed house is 91.69m² for each story and 275.07 for the whole building.

Table 33: Energy consumption of existing and newly designed buildings

<table>
<tr><th colspan="2">Perspective</th><th colspan="3" rowspan="2"></th></tr>
<tr><th>Summer (15 June-14 h)</th><th>Winter (15 December-14 h)</th></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>268.10</td><td>11.40</td><td>279.51</td></tr>
<tr><td colspan="3">1 (Existing Building)</td></tr>
<tr><td colspan="3">Uninsulated wall & Roof
Single glazing
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>60.67</td><td>5.53</td><td>66.20</td></tr>
<tr><td colspan="3">1+Insulated wall</td></tr>
<tr><td colspan="3">Insulated wall & Roof
Single glazing
Internal Blinds
Best practice wall</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>59.17</td><td>4.63</td><td>63.80</td></tr>
<tr><td colspan="3">1+ Insulated wall & window</td></tr>
<tr><td colspan="3">Insulated wall & Roof
Triple glazing
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>44.18</td><td>16.30</td><td>60.49</td></tr>
<tr><td colspan="3">2 (West-facing)</td></tr>
<tr><td colspan="3">West-facing
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>39.82</td><td>18.43</td><td>58.25</td></tr>
<tr><td colspan="3">2 (East-facing)</td></tr>
<tr><td colspan="3">East-facing
1m Overhang
Internal Blinds</td></tr>
</table>

		Energy Demand (kWh/m²a) **Heating** | **Cooling** | **Total** **47.71** | **10.21** | **57.92** **2 (North-facing)** North-facing 1m Overhang Internal Blinds
		Energy Demand (kWh/m²a) **Heating** | **Cooling** | **Total** **40.33** | **17.35** | **57.68** **9 + N+E+W window (4 story)** Pitched Roof - Skylight No Overhang External Controlled Blinds 4 story on earth
		Energy Demand (kWh/m²a) **Heating** | **Cooling** | **Total** **43.35** | **9.85** | **53.20** **2 (1 Story)** 1m Overhang Internal Blinds 1 Story
		Energy Demand (kWh/m²a) **Heating** | **Cooling** | **Total** **21.94** | **30.41** | **52.35** **4 + Attic + Large skylight (5)** Pitched Roof - Skylight 1m Overhang Internal Blinds
		Energy Demand (kWh/m²a) **Heating** | **Cooling** | **Total** **21.39** | **28.37** | **49.76** **5 + Controlled blinds** Pitched Roof - Skylight 1m Overhang External high reflective controlled Blinds

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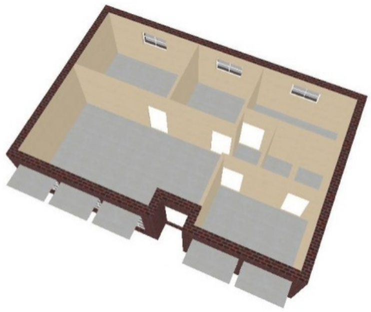
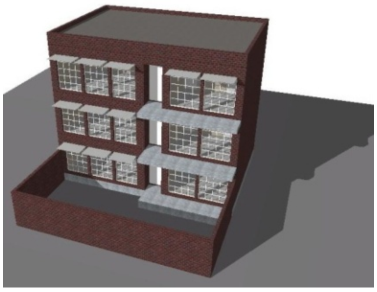
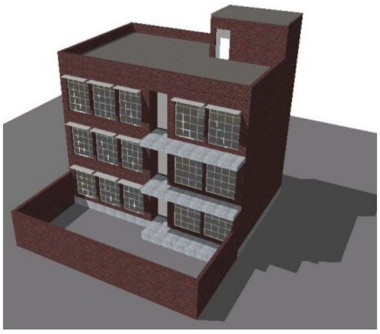
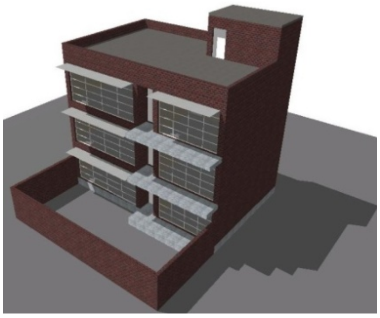
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>30.70</td><td>11.20</td><td>41.90</td></tr>
<tr><td colspan="3">2 + Non door buffer zone</td></tr>
<tr><td colspan="3">Non door buffer zone
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>28.66</td><td>11.50</td><td>40.16</td></tr>
<tr><td colspan="3">2 + No Staircase</td></tr>
<tr><td colspan="3">No Staircase
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>28.47</td><td>11.13</td><td>39.60</td></tr>
<tr><td colspan="3">2 (Designed Building)</td></tr>
<tr><td colspan="3">1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>27.45</td><td>12.08</td><td>39.54</td></tr>
<tr><td colspan="3">3 + Skylight (4)</td></tr>
<tr><td colspan="3">Pitched Roof - Skylight
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>27.11</td><td>11.02</td><td>38.12</td></tr>
<tr><td colspan="3">2 + Pitched roof (3)</td></tr>
<tr><td colspan="3">Pitched Roof
1m Overhang
Internal Blinds</td></tr>
</table>

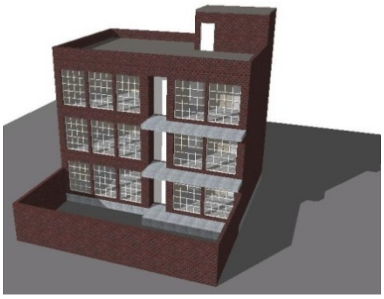
Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
26.74	**11.28**	**38.02**
2 + No Blinds		
1m Overhang No Blinds		



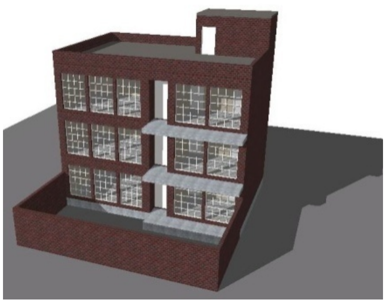
Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
25.42	**12.32**	**37.74**
2 + 0.5m Overhang		
0.5m Overhang Internal Blinds		



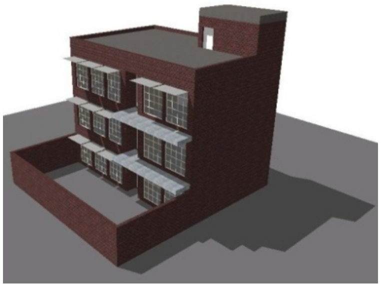
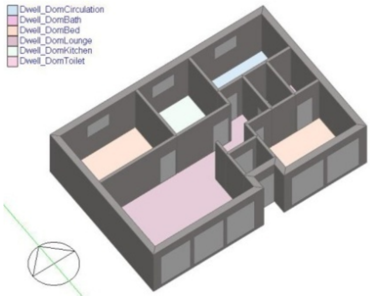
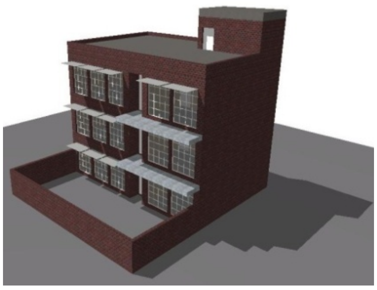
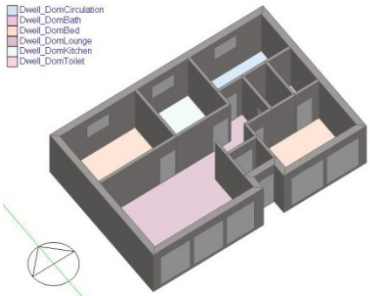
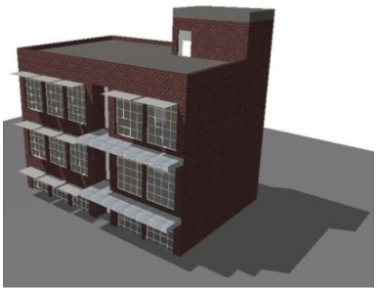
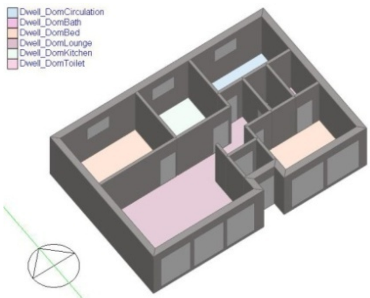
Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
22.59	**14.50**	**37.09**
2 + Large South window		
Large South window 1m Overhang Internal Blinds		

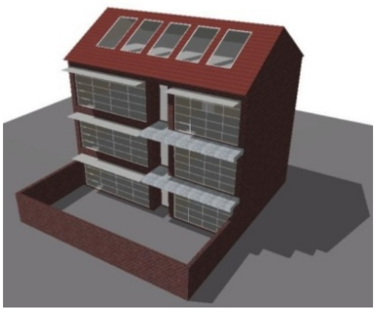


Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
20.92	**15.99**	**36.91**
2 + No Overhang		
No Overhang Internal Blinds		



Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
18.77	**16.26**	**35.03**
2 + No Overhang & Blinds		
No Overhang No Blinds		

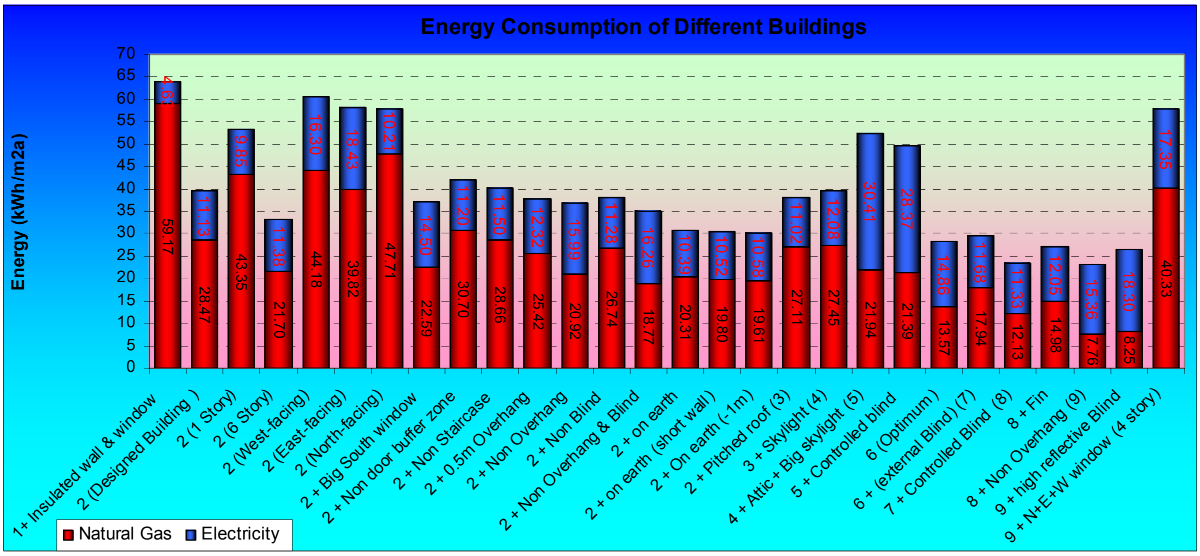
<table>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>21.70</td><td>11.38</td><td>33.08</td></tr>
<tr><td colspan="3">2 (6 Story)</td></tr>
<tr><td colspan="3">6 Story
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5">
</td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>20.31</td><td>10.39</td><td>30.69</td></tr>
<tr><td colspan="3">2 + on earth</td></tr>
<tr><td colspan="3">on earth
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5">
</td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>19.80</td><td>10.52</td><td>30.31</td></tr>
<tr><td colspan="3">2+ on earth (short wall)</td></tr>
<tr><td colspan="3">on earth
short courtyard wall
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5">
</td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>19.61</td><td>10.58</td><td>30.19</td></tr>
<tr><td colspan="3">2 + On earth (-1m)</td></tr>
<tr><td colspan="3">On earth (-1m)
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>17.94</td><td>11.68</td><td>29.63</td></tr>
<tr><td colspan="3">7 (6 + exterior blinds)</td></tr>
<tr><td colspan="3">On earth
Pitched roof - Skylight
1m Overhang
External Blinds</td></tr>
</table>

<table>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>13.57</td><td>14.86</td><td>28.43</td></tr>
<tr><td colspan="3">6 (Optimum)</td></tr>
<tr><td colspan="3">On earth
Pitched roof - Skylight
1m Overhang
Internal Blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>14.98</td><td>12.05</td><td>27.03</td></tr>
<tr><td colspan="3">8 + Fin</td></tr>
<tr><td colspan="3">On earth
Pitched roof - Skylight
1m Overhang - 1m Fin
External controlled blinds</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>8.25</td><td>18.30</td><td>26.55</td></tr>
<tr><td colspan="3">9+ Highly reflective blinds</td></tr>
<tr><td colspan="3">On earth
Pitched roof - Skylight
External high reflective controlled
Blinds - No Overhang</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>12.13</td><td>11.33</td><td>23.47</td></tr>
<tr><td colspan="3">7 + Controlled Blinds (8)</td></tr>
<tr><td colspan="3">On earth
Pitched roof - Skylight
External controlled Blinds
1m Overhang</td></tr>
<tr><td rowspan="5"></td><td rowspan="5"></td><td colspan="3">Energy Demand (kWh/m²a)</td></tr>
<tr><td>Heating</td><td>Cooling</td><td>Total</td></tr>
<tr><td>7.76</td><td>15.36</td><td>23.12</td></tr>
<tr><td colspan="3">8 + No Overhang (9)</td></tr>
<tr><td colspan="3">On earth
Pitched roof - Skylight
External controlled Blinds
No Overhang</td></tr>
</table>

Comparison of Energy Demand of All Simulated Buildings

The following diagram compares the heating and cooling energy demand of the different simulated buildings. All these buildings have similar constructional characteristics and differ only in architectural design.

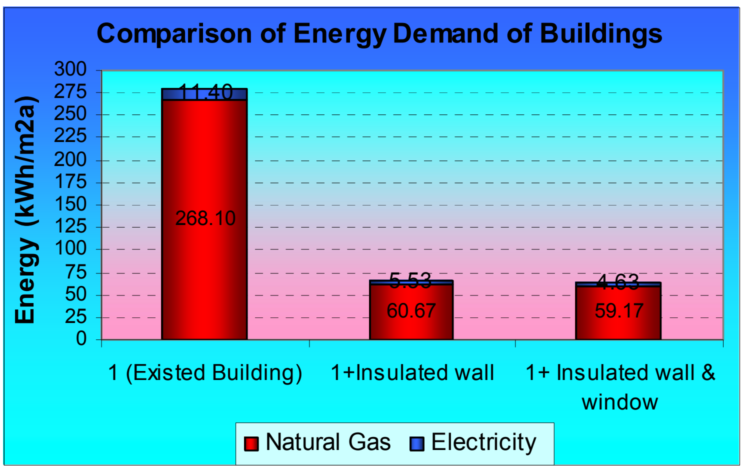
The energy demand of the most efficient building is 64% less than the least efficient building in similar control conditions but only with architectural design as the variable factor. It shows that architectural characteristics have a great impact on cooling and heating energy demand.



Comparison of Energy Demands of Similar Buildings

Effect of Insulation on Energy Consumption

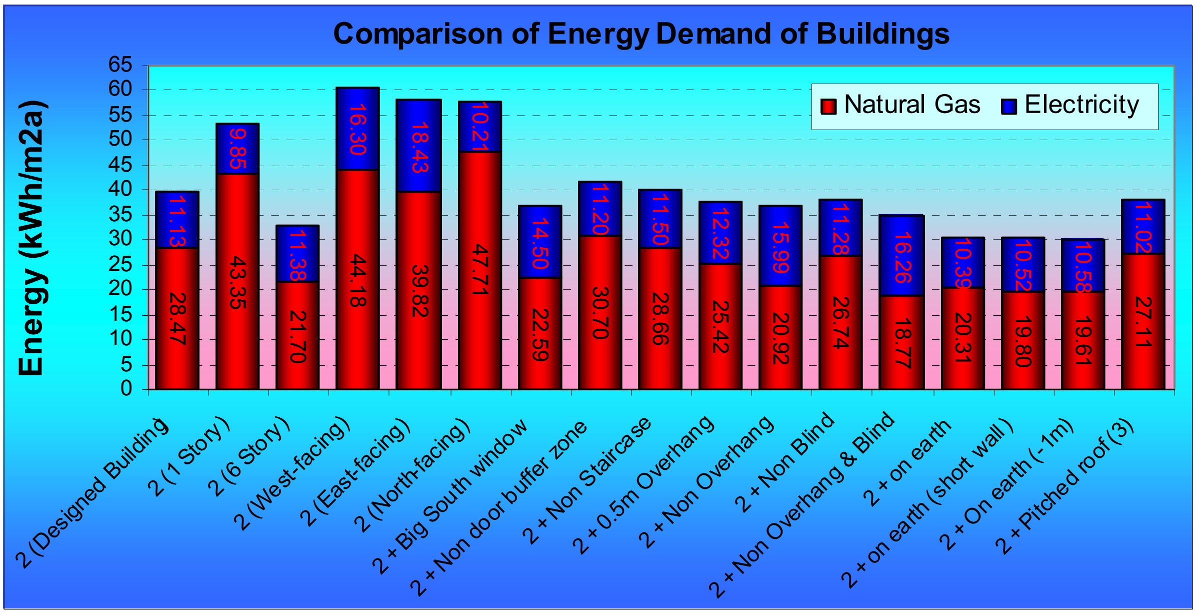
The following diagram compares the energy demand of the existing building and the same building with an insulated opaque envelope and triple glazed windows. It shows that insulating windows and especially using an opaque thermal envelope (walls, roofs and floors) effectively reduces energy consumption.



Comparison of Building 2 and Similar Buildings

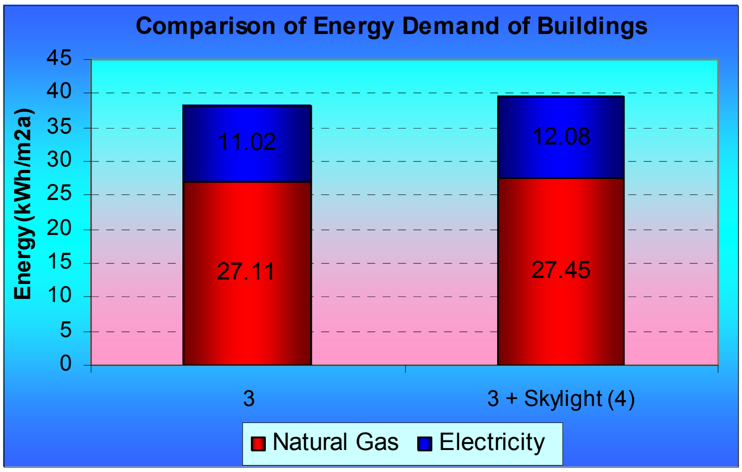
The following diagram compares buildings 2 and similar ones in their energy demand. It shows that:

- Increasing the number of floors of a building reduces the amount of energy expenditure.
- Orientation of the building, elongation, the amount of windows in every direction, etc. significantly effect its energy consumption. Of the four main orientations, south is the most appropriate for buildings in Tabriz.
- Increasing the amount of south-facing windows increases the cooling energy, however it more significantly reduces the heating energy and total energy consumption.
- Thermal buffer zones for external doors reduce the amount of energy consumption.
- Locating the building on the ground level or a part of the building under the ground reduces energy consumption.
- Having pitched roofs instead of flat roofs reduces energy consumption.



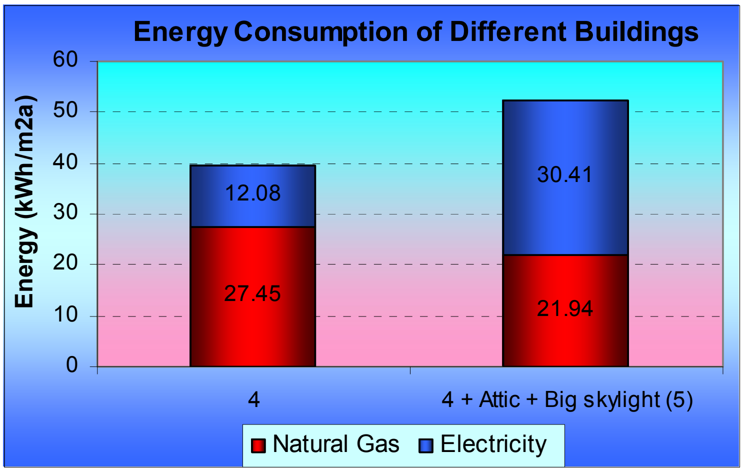
Comparison of Building 3 and a Similar Building

The building which has skylights with internal blinds located on the pitched roof of a non-residential attic, has greater heating and cooling energy demands than the same building without skylights. Therefore, such skylights increase the energy consumption.



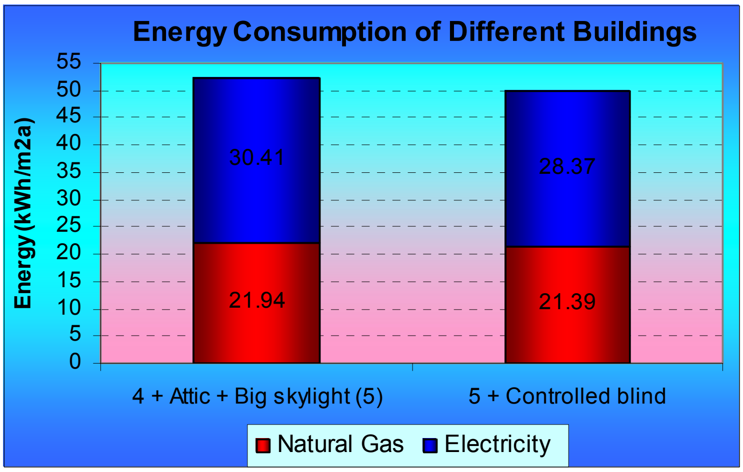
Comparison of Building 4 and a Similar Building

In the following diagram, the comparison of buildings, with and without residential attics and large skylights without shading devices on the roof, shows that large skylights (without shading devices) on pitched roofs of residential attics decrease heating energy demand but increase cooling energy requirements more significantly and thus lead to increases in total energy demand of buildings.



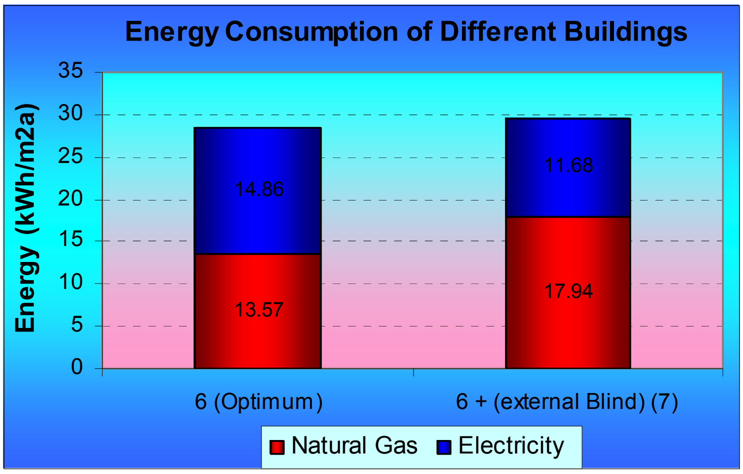
Comparison of Building 5 with a Similar Building

According to the following diagram, external blinds (controlled according to cooling and heating energy needs) reduce both heating and cooling energy consumption of the building. Controlled external blinds reduce cooling energy because they decrease solar heat gain in cooling period and decrease heating energy demand in winter. This is because closing blinds during winter nights prevents radiation of heat (long-wave energy) to cold, outdoor spaces.



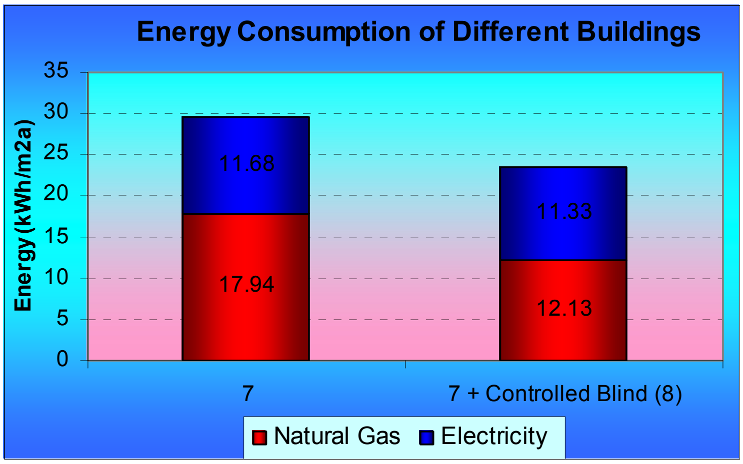
Comparison of Building 6 with a Similar Building

Comparison of energy demand of building 6 with a similar building with external blinds shows that, though the external closed blinds (or blinds which are not controlled according to heating and cooling energy demand) reduce cooling energy, they simultaneously increase (to a greater degree) heating energy and thus total energy consumption. It also shows that, in comparison with internal shading devices, external shading devices are more effective in reducing cooling energy.



Comparison of Building 7 with a Similar Building

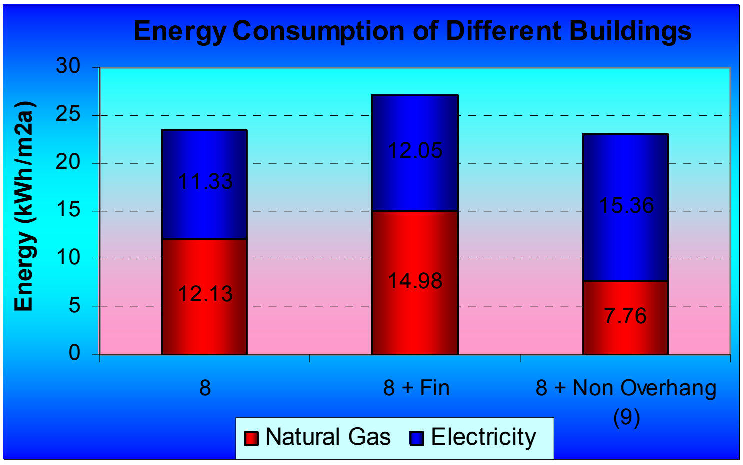
In the graph below, one building with controlled and uncontrolled external shading devices is compared. It shows that controlling the blinds according to cooling and heating energy needs effectively reduces energy consumption (especially heating energy). Opening and closing the blinds according to heating and cooling energy needs during different seasons, and day and night, is crucial in reducing energy consumption of the building.



Comparison of Building 8 with Similar Buildings

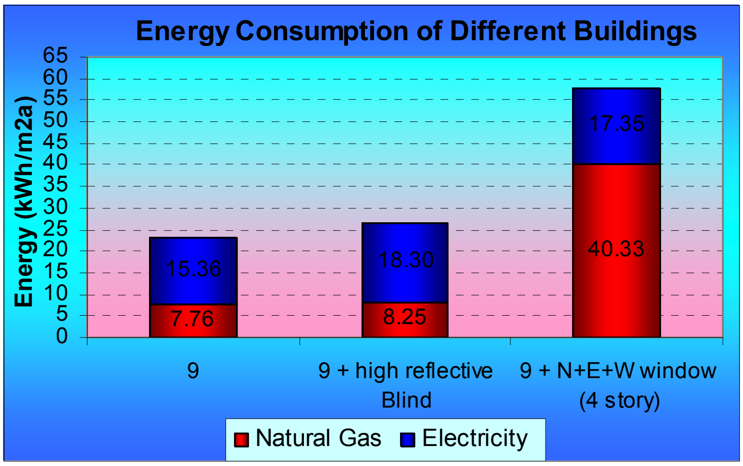
Energy demand of three buildings with and without overhangs and also with fins over south-facing windows is compared in the following diagram. The windows of these buildings also have external blinds. It proves that using fins over south-facing windows with external blinds increases the amount of energy consumption.

Using 1m overhangs at south-facing windows which also have external blinds reduces cooling energy but increases heating energy consumption. It slightly increases total energy consumption. However, because cooling buildings is more difficult and more expensive than heating, the use of overhangs for south-facing windows is recommended, even when these windows have external blinds. The optimum dimension of overhangs must be calculated with regard to window dimensions in order to decrease the total energy consumption of a building.



Comparison of Building 9 and Similar Buildings

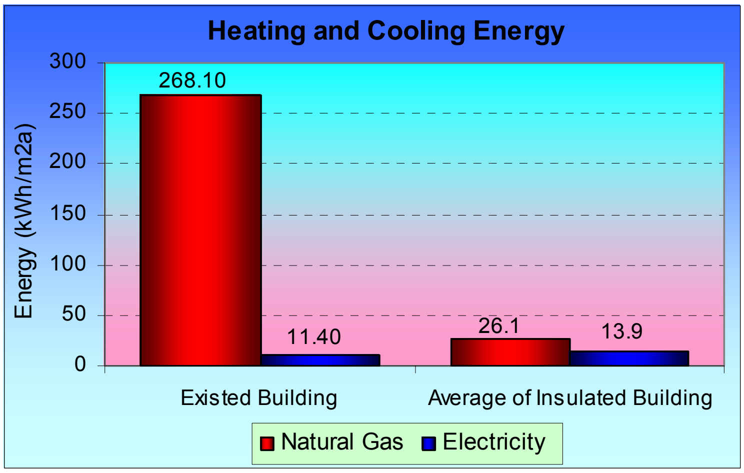
The simulation of buildings presented in this graph shows that north-, east- and west-facing windows in buildings with a large area of south-facing windows and also highly reflective blinds, increase the energy consumption of the building.



Comparison of Heating and Cooling Energy Demands

Comparison of an Existing Building and Other Insulated Buildings

The following diagram compares heating and cooling energy in existing buildings and in insulated buildings which have less energy consumption. It shows that the insulated buildings only have less heating energy consumption but no less cooling energy consumption. By designing a cold climatic responsive house, only the amount of heating energy will be effectively decreased.

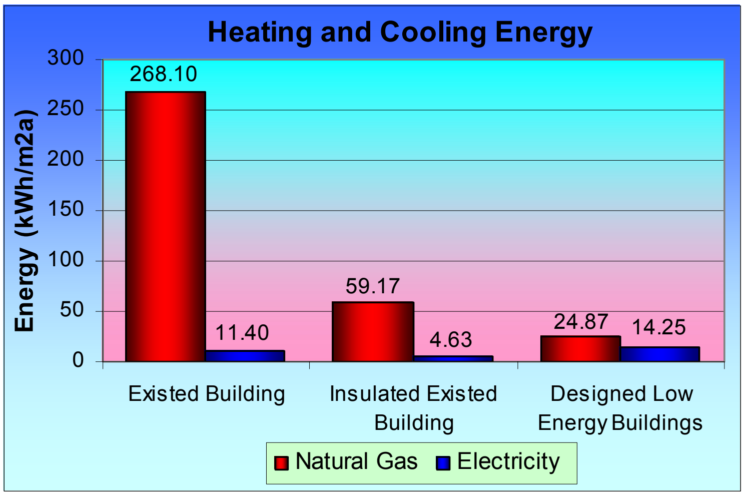


The typical uninsulated building in Tabriz annually consume heating energy 23.5 times more than cooling energy. But in climatically designed buildings, the amount of heating energy is only a little bit more than cooling energy.

Comparison of Insulated and Uninsulated Existing Buildings and Other Insulated Designed Buildings

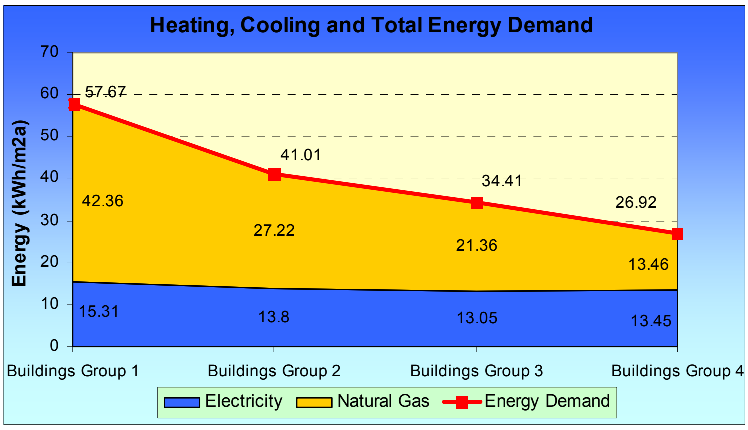
This diagram shows the amount of heating and cooling energy in uninsulated existing buildings, insulated existing buildings and some climatically designed buildings. It shows that insulating the building reduces the cooling (59%) and especially heating (78%) energy demand. Naturally, this figure is dependent on the building type.

Climate responsive buildings which have been designed for cold climates have less heating and total energy demand but not less cooling energy demand, because these buildings also have higher external heat gains in summer. Therefore, in these buildings cooling is very important.



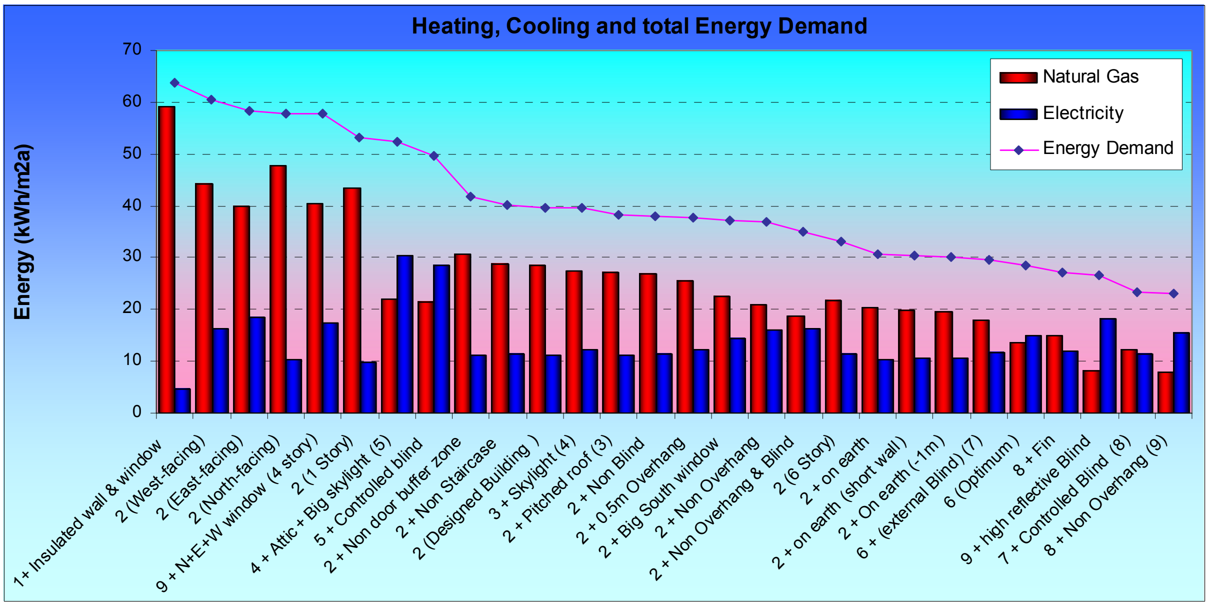
Comparison of Insulated Designed Buildings (in Four Groups)

The following diagram compares the amount of cooling, heating and total energy demand of four groups of buildings that are different in their total energy consumption. It shows that reducing the energy demand in these buildings is only achieved by reducing heating energy demand.



Comparison of Heating, Cooling and Total Energy Demands of Insulated Buildings

Diagram below shows that by reducing the energy demand of different buildings, only the amount of heating energy is decreased and the difference between the heating and cooling energy will also be decreased. Decreasing the energy demand is done through decreasing the heating energy. If the cooling energy demand of these buildings can be reduced too, their energy demand will decrease more effectively.



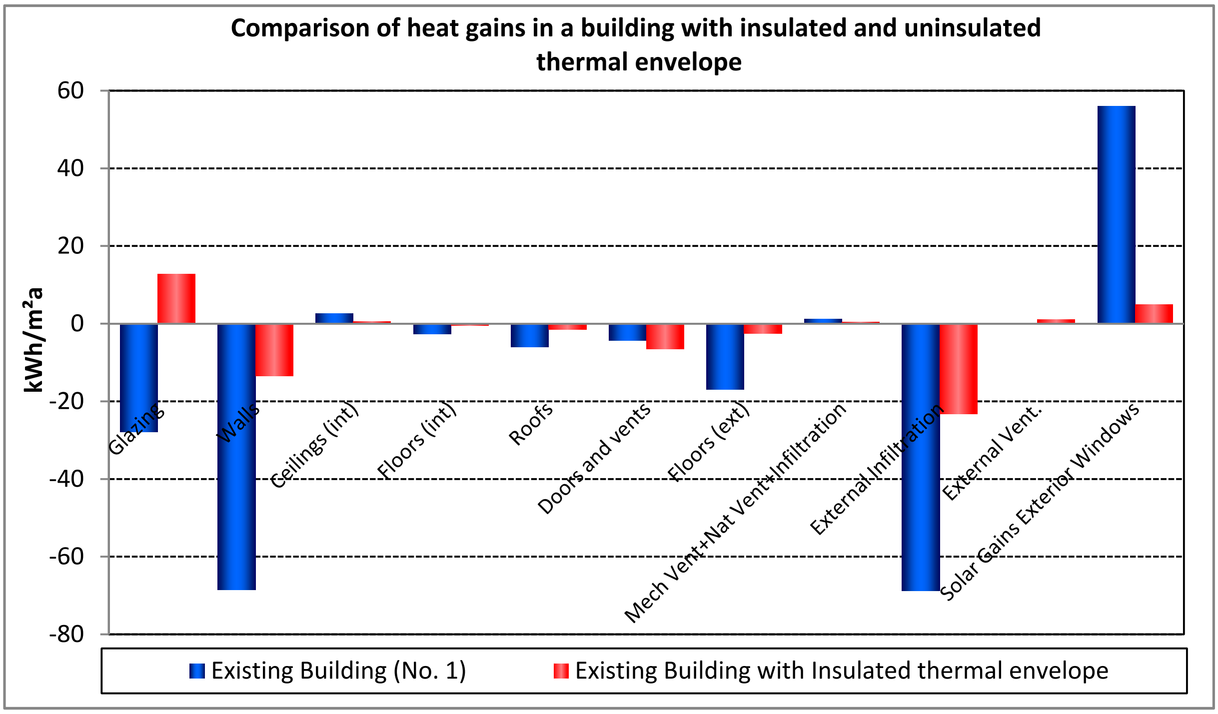
Comparison of the Least and the Most Efficient Buildings

The following table shows the heat gains and the system energy need of existing building (building 1), existing building with insulated thermal envelope and a recommended energy efficient building (building 8). The solar heat gain through windows in the energy efficient building (51.08 kWh/m²) is 4.5 times more than its natural gas consumption for heating (19.47 kWh/m²).

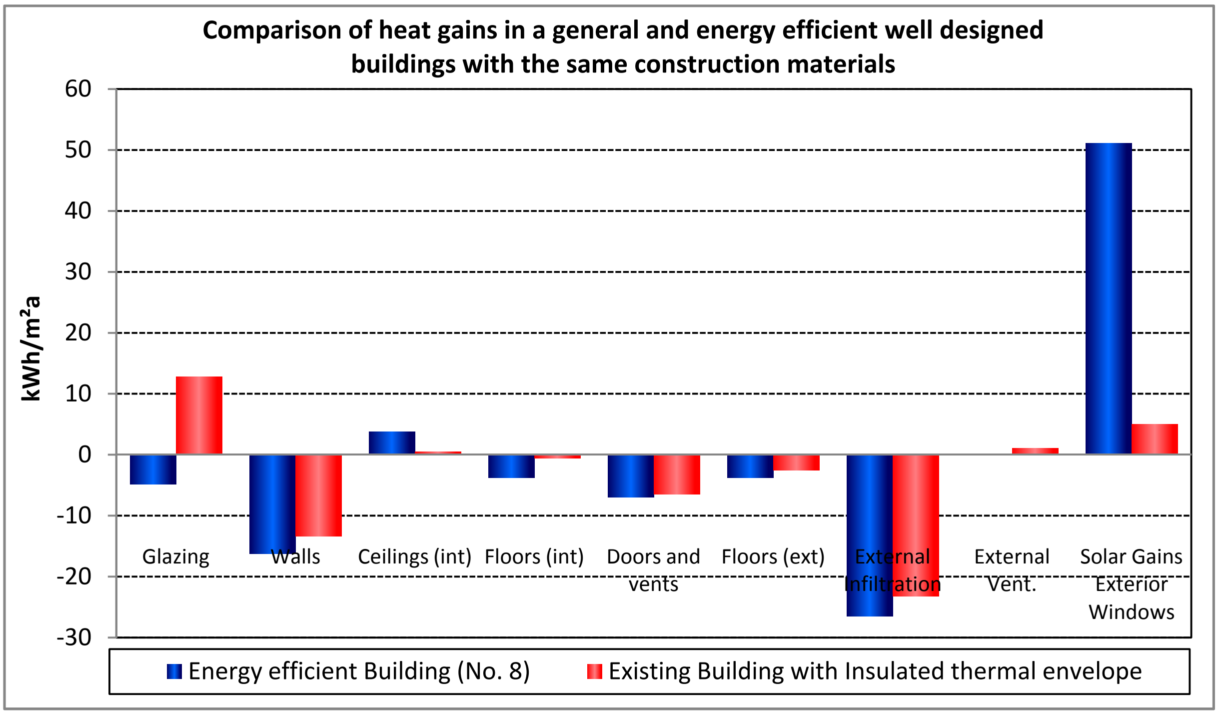
Table 34: Amount of annual heat gains and system energy need of in Existing Building (No.1), Existing Building with Insulated Thermal Envelope and Energy Efficient Building (No.8)

	Glazing	Walls	Ceilings (internal)	Floors (internal)	Partitions (internal)	Roofs	Doors and vents	Floors (external)	External Infiltration	External Ventilation	Occupancy	Solar Gains Exterior Windows	Zone/Sys Sensible Heating	Zone/Sys Sensible Cooling	System Misc	Heat Generation (Gas)	Chiller (Electricity)
Building	kWh/m²																
Existing Building (No.1)	-27,8832	-68,5014	2,649123	-2,68756	-4,86E-03	-6,00711	-4,30386	-16,9655	-68,8424	-9,82E-03	3,055922	56,02841	162,2816	-29,0232	3,26	279,796	11,60929
Existing Building with Insulated thermal envelope	12,80646	-13,406	0,510044	-0,52804	-1,42E-02	-1,47986	-6,50388	-2,51644	-23,2459	1,038751	3,044441	4,993173	36,27148	-10,7647	3,26	62,53704	4,305873
Energy efficient Building (No.8)	-4,83008	-16,2143	3,775804	-3,76792	-9,97E-02	---	-6,94238	-3,76162	-26,4828	-3,01E-02	3,69826	51,08564	11,29396	-28,256	3,26	19,47234	11,30239

The following graph compares the heat gains and heat losses through different building components in the existing buildings with insulated and uninsulated thermal envelopes. It shows that the heat gains and heat losses through different building components are completely different in these two buildings and is much more in glazings, walls, external floors and external infiltrations. It also shows that in uninsulated buildings, the walls, the external infiltration, and glazings have the highest heat losses. Therefore reducing the heat loss through these three factors is of the most importance.



The following graph compares the gains and losses of heat through different architectural components of existing house with insulated thermal envelope and a well-designed building (No.8) with the same construction materials.



It shows that two factors, that is, glazing and the solar gain through the exterior window are most highly different. It suggests the important and critical role of windows and shading devices in designing energy efficient buildings. It also indicates that in insulated buildings, external infiltration causes a high amount of heat loss. Therefore; it is critical to airtight the thermal envelope of buildings.

The following graphs show the daily heat gains and energy consumption of Existing Building (building 1), Existing Building with Insulated thermal envelope and Energy efficient Building (building 8).

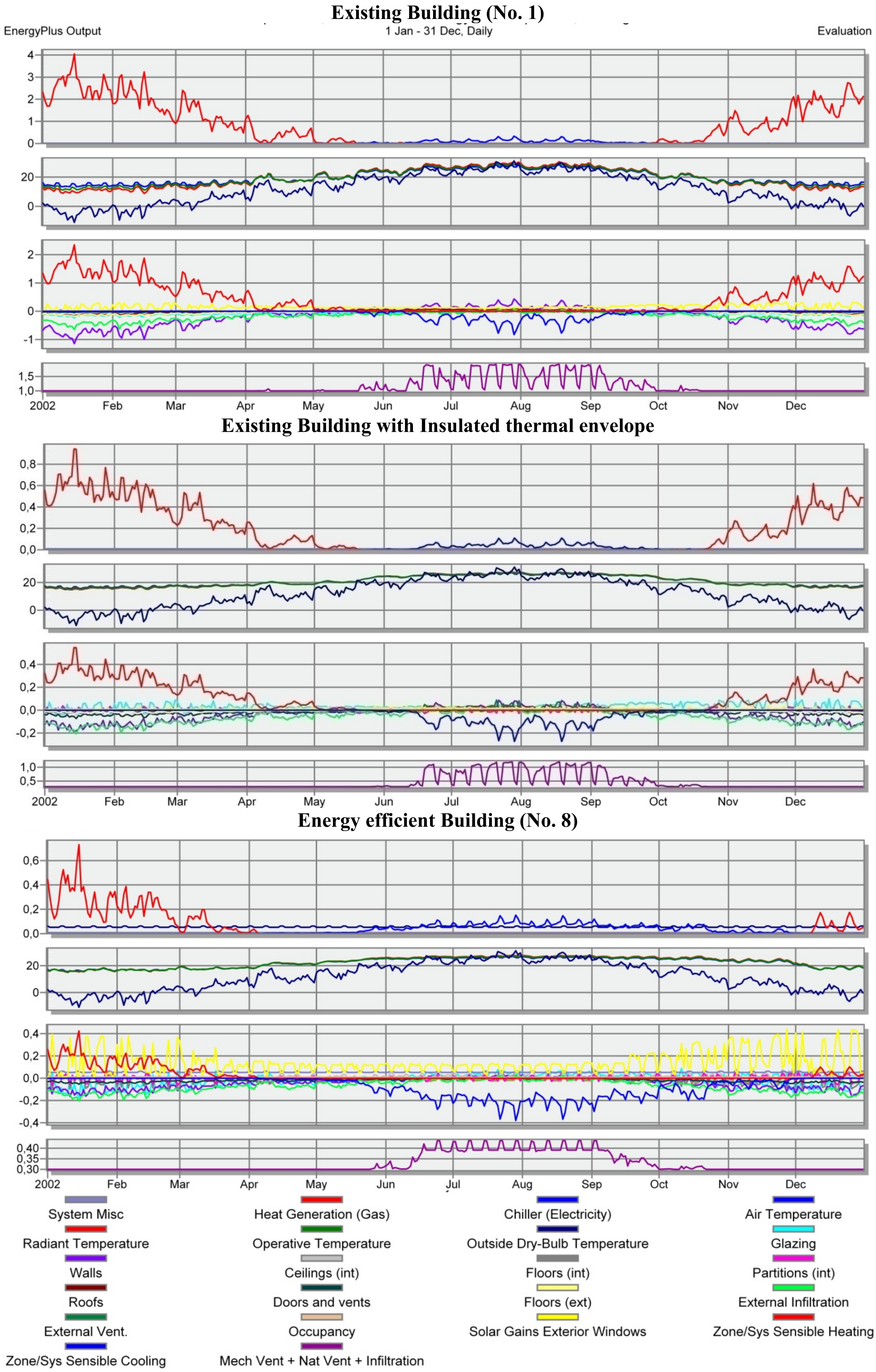
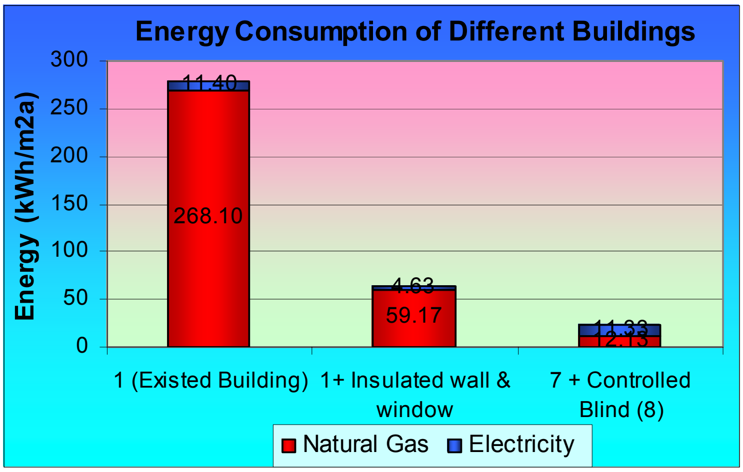


Figure 104: Daily graphs of the heat gains and energy consumption of Existing Building (No.1), Existing Building with Insulated Thermal Envelope and Energy Efficient Building (No.8)

Results

This diagram presents the difference between the energy demands of the existing building, the same building with insulated thermal envelope, and a designed building. In these three buildings, the energy consumption of a residential building in Tabriz will decrease effectively through the application of insulation material in the thermal envelope. This is particularly true for the insulated, well designed building. The energy consumption of our given building in Tabriz is twelve times higher than the similar well-designed and insulated building there (with nothing added to it).

The heating energy consumption of this building is 7.76kWh/m²a which falls within the passive house category and thus it needs no conventional heating system, which effectively reduces the building cost.



Simulation and analysis shows that insulation of the thermal envelope of buildings, and the use of insulated windows will effectively reduce the energy demand of the building. For example, the energy demand of the existing building is reduced about 77% only by insulating the thermal envelope.

The architectural design of buildings also greatly affects their energy demand, this is rarely considered. In the simulated buildings, the architectural design has reduced energy demand of the building from 63.80 to 23.12kWh/m²a

The following factors reduce the energy demand of buildings in cold climates:

- Insulating the thermal envelope
- Increasing the number of floors
- Orientation to south, and east-west elongation
- Increasing the amount of south-facing windows
- Thermal buffer zones for external doors
- Locating the building on the ground level or a part of the building under the ground
- Having a pitched roof instead of flat roof

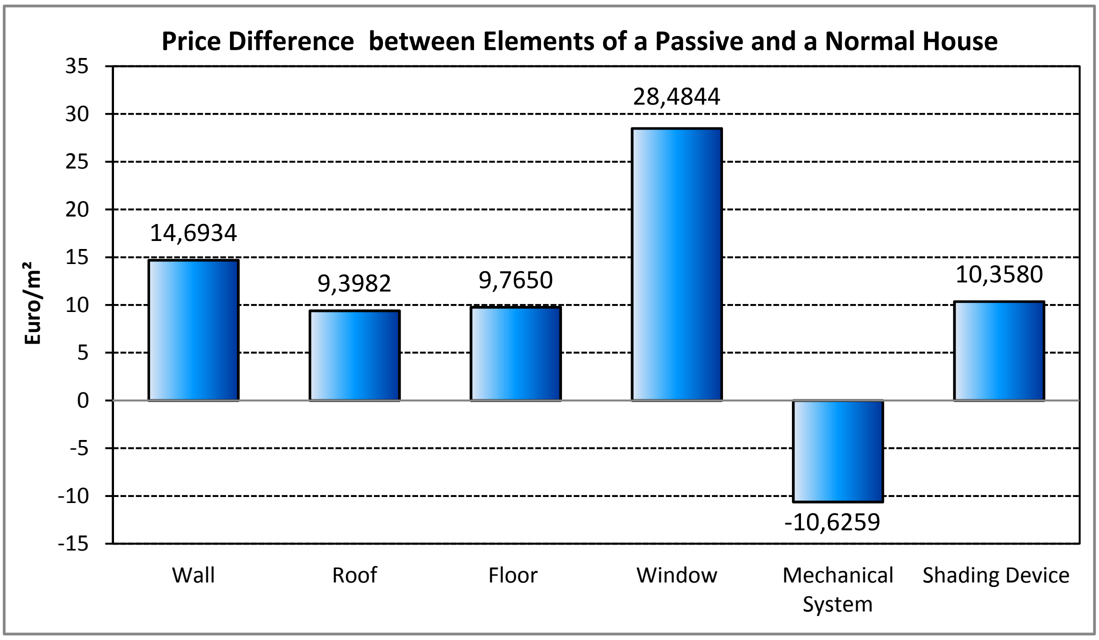
- Use of external shading devices instead of internal shading devices, especially external movable shading devices
- Controlling the movable shading devices according to cooling and heating energy needs
- Use of overhangs with optimum dimensions for south-facing windows, even for windows which have external blinds

The following factors increase the energy demand of buildings in cold climates:

- North, east and west-facing windows in buildings with large areas of south-facing windows
- Skylights with internal blinds in pitched roofs of non-residential attics
- Skylights without shading devices in pitched roof of residential attics
- Large skylights in pitched roofs of residential attics, especially whose shading devices are not controlled according to heating and cooling energy needs
- Using fins at south-facing windows
- External closed blinds, or blinds which are not controlled according to required heating and cooling energy

Economic Analysis

For economic analysis of the use of passive houses in Iran, in which the energy price is very low, a newly designed passive house is economically compared to a house that is architecturally and structurally similar to existing buildings in Iran's cold climate and has more energy consumption. The construction costs of these two buildings are compared to find the cost difference. In these two buildings, walls, roof, floor, windows, shading devices, and heating and cooling systems are different, and other parts of the buildings are the same. Therefore, to find the price difference between these two buildings, the cost of different construction elements and mechanical systems is calculated and compared. The following graph presents the cost difference of different elements for 1m² of these two buildings.



Cost difference of building elements for 1m² of an existing normal house and a newly designed passive house, Source: Management and Planning Organization of Iran 2006a, pp.1-160 and 2006b, pp.1-136 (my calculations and inferences)

Walls, roof and floor of the new, low energy house are more expensive than the normal house, because of the use of insulation materials. The windows of the passive house have triple glazing and insulated frames while the windows of the normal house are single glazed and therefore more expensive. The windows have the greatest cost difference among all construction and mechanical elements of these two buildings, because the insulated triple glazed windows are very expensive in comparison to general windows and the building has very high window area (to passively use solar energy). Only the heating and cooling system of the low energy house is cheaper than the normal house because the new building has less energy demand and needs smaller heating and cooling systems.

The total construction cost of a new, low energy house in Iran is more than a normal house. In 2006, the cost of building a passive house in Iran was 62.07

Euro/m²[1] (713096.7 Rial/m²)[2] more than building a similar normal house. The average building cost in Iran in 2006 was 125.85Euro/m² (1478000 Rial/m² (Central Bank of Iran 2007a)) and thus the costs of constructing a passive house in Iran is 187.92 Euro/m² (2191096.7 Rial/m²). Therefore, constructing a passive house in Iran will cost 50% more than a normal house. Although the passive house used for cost calculations has an energy efficient architectural design and needs only about 12cm of insulation material, it has a high cost difference (50%) compared with a normal house. This is because construction material is expensive in Iran and because normal houses are generally built without insulation material, with single glazed windows, etc. There is, therefore, a high construction cost difference between normal and (energy efficient or) passive houses in Iran.

Initial investment costs, annual energy saving, energy costs, annual operation costs, considered period of time (utilization) and some economic factors of Iran such as interest rate, inflation rate (general) and energy inflation rate will be considered to calculate the payback time and internal interest rate of the investment. The payback time and internal interest rate of the investment are the important figures for economic efficiency and will be used to decide whether or not the construction of a passive house with low energy consumption in Iran is economically viable.

"The first condition for efficiency is that the payback time must be shorter than the life time of the system, resp. the considered period of time (utilization). If this condition is met, the internal interest rate is a second figure to assess the economic efficiency of an investment. It depends on the considered period of time. The internal interest rate should be larger than or equal to the interest rate for the capital investment. In this case, the input value "interest rate" has no influence on the calculation of the internal interest. For the first case, the payback time depends on the interest rate for capital investment given by the user. Here, the considered period of time has no influence on the results" (Heidt 11.04.2008).

To economically evaluate and analyse the use of passive houses in Iran, software called Economic Evaluation (Oeko-Rat) is used. This software is especially designed for calculations of the economics of energy saving and renewable energies and evaluates the economic efficiency of an investment according to the capital value method.

Because the energy price in Iran is significantly less than other countries (due to government energy subsidies), the economic evaluation is done both with energy price in Iran and average energy price in other countries. The following information about initial investment, energy and economic factors for Iran and the average energy price and energy inflation rate of other countries is used for economic simulation.

The total cost difference of normal and low energy houses is used as initial investment costs and the annual energy saving is the annual difference of energy

[1] - 1 Euro is in years 2005, 2006 and 2007 respectively 11164, 11488 and 12732 Rial (Central Bank of the Islamic Republic of Iran, 15.05.2008).

[2] - The rial (IRR/Iran Rials) is the currency of Iran.

consumption of these two houses, which are calculated through simulation.

Table 35: Amount of factors used for economic evaluation in Iran and world average

Factor	Iran 2006	World
Initial investment costs (Rial)	230027179.8	230027179.8
Annual energy saving (kWh)	70686.21022	70686.21022
Energy costs (Natural Gas and Electricity) (Rial/kWh)	90.0893 (1)	783.296 (5)
Annual operation costs (%)	2	2
Considered period of time (utilization) (Years)	30	30
Interest rate	17 (2)	17
Inflation rate (general) (%)	12.1 (3)	12.1
Energy inflation rate (Natural Gas and Electricity) (%)	12.1(4)	14.585 (6)

Source:
1: Based on data from Iran Ministry of Energy 2006, p.11, Table 1-1
2: Based on data from Omidvar 09.05.2005
3: Based on data from Fars News Agency 05.11.2007
4: Based on data from Iran Ministry of Energy 2006, p.10
5: Based on data from Energy Information Administration 07.06.2007, Iran Ministry of Energy 2006, p.495, Table 9-51 and p.456, Table 9-27
6: Based on data from International Energy Agency 10.11.2007

Economic Evaluation with the Energy Price in Iran

The economic evaluation with the energy price in Iran shows that the investment for building a passive house instead of a normal house in Iran is not economically viable because the payback time for this investment is not less than the considered period of time (utilization time) of this house. This is because the energy price in Iran is very low in comparison to the worldwide energy price. The internal interest rate of such investment is also 2.9%, which is less than the general interest rate.

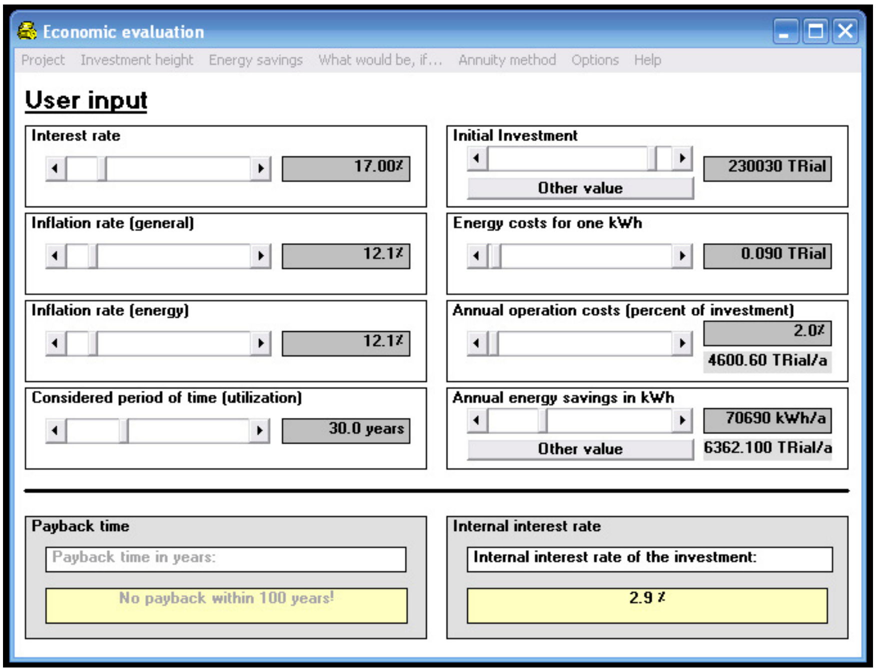


Table 36: Factors of economic efficiency for energy investment in Iran

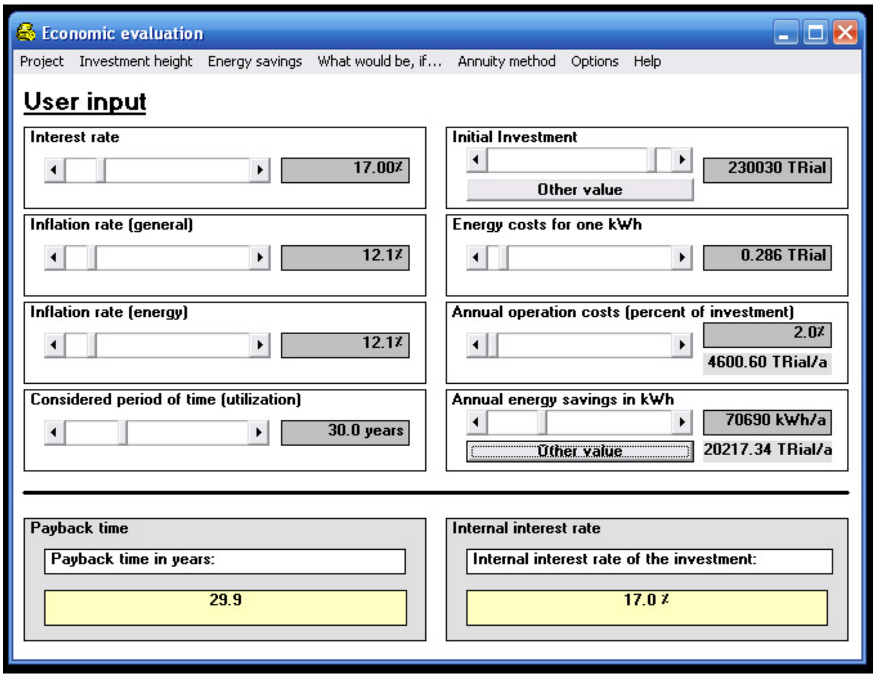
Considered period of time	Payback Time	Interest rate	Internal interest rate of the investment	Result
30 Years	**>100 Years**	17%	**2.9%**	**Uneconomic**

For this project to be economically viable, the specific energy costs must exceed 286 Rial/kWh or the inflation rate for energy must exceed 21.51%. Another way to make the construction of low energy houses in Iran economically viable is through an initial amount of support exceeding 157733410 Rial, for example as a subsidy. Alternatively, the initial investment must be 157733410 Rial less than our investment (the initial investment must be 72300000 Rial).

Table 37: Cost and inflation rate of energy and initial investment in existing conditions, and conditions in which the investment is economic

	Specific energy cost (Rial/kWh)	Inflation rate of energy (%)	Initial investment (Rial)
Existing Condition	90	12.1	230 030 000
Needed Condition	286	21.51	72 300 000

With such conditions, the paypback time is less than the considered period of time of the investment and the initial interest rate of the investment is equal with the general interest rate. Thus the investment is economically viable.



Economic Evaluation with the Average Energy Price of other Countries

Because of Iran's energy subsidies and the resulting low energy price, economic evaluation with the average energy price of other countries is valid and reliable. The economic evaluation with the average energy price of other countries shows that, under these circumstances, the investment for building a passive house in Iran is economically very viable. The payback time for replacement of a passive house and a normal house is 5.6 years, which is very short. The internal interest rate of such an investment is also 36.6%, which is not only very high but also much higher than the general interest rate.

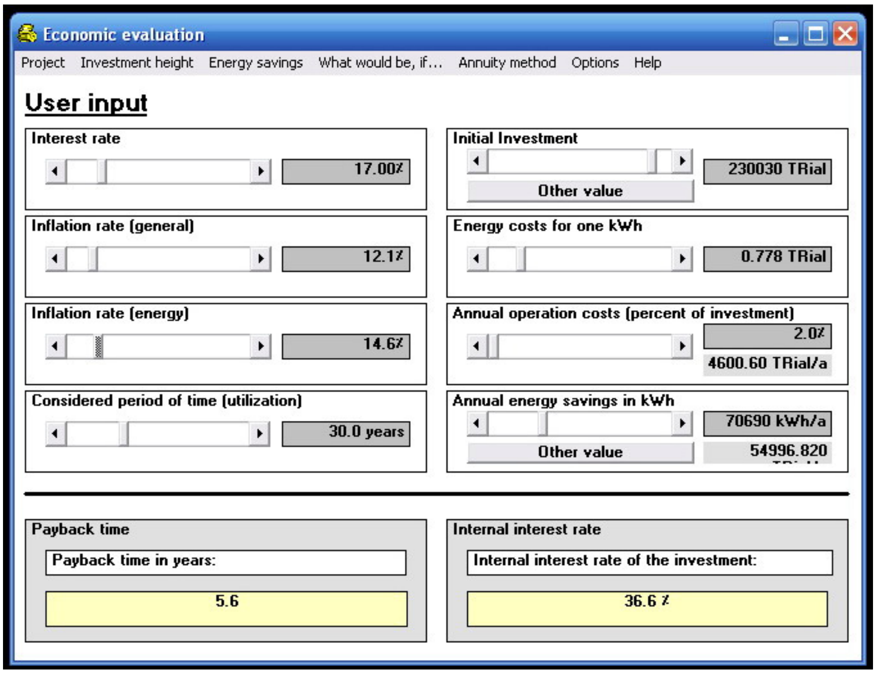
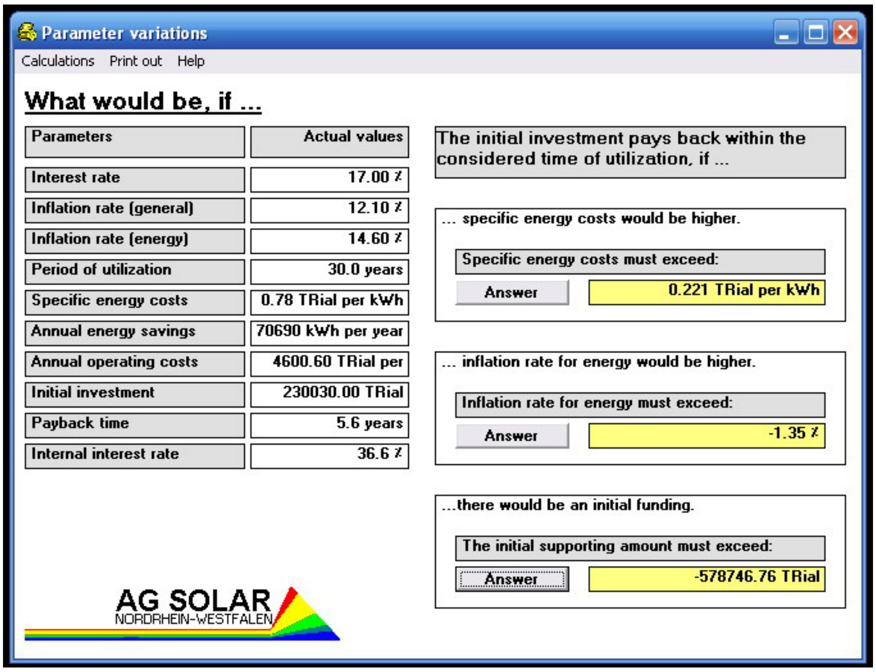


Table 38: Factors of economic efficiency for energy investment in Iran

Considered period of time	Payback Time	Interest rate	Internal interest rate of the investment	Result
30 Year	**5.6 Year**	17%	**36.6%**	**Economic**

Even if the energy price was 221 Rial/kWh, or if the inflation rate for energy was -1.35%, or if the investment was 578746760 more than the initial investment, the project would still be economically viable.



Heating and Cooling Mechanical Equipment (HVAC System)

Introduction

This section of the research studies the heating and cooling systems and their different classifications. It tries to select climatically, economically and technologically suitable HVAC systems for energy-efficient and passive houses in Iran.

HVAC stands for heating, ventilating and air conditioning, and is used to refer to those mechanical systems which provide space conditioning (Washington State Dept. of General Administration 2007, p.8). HVAC systems are used for the maintenance of air temperature, relative humidity and air quality. Heating and cooling (air conditioning) systems are two important components of HVAC system, which are used for the stabilization of air temperature and relative humidity of indoor environment within the comfort zone.

Heating Systems

Classification of Central Heating Systems Based on Fuel Type

Based on fuel type there are two different central heating systems:

1. Fossil fuel systems: include most central heating systems. They use fossil fuels such as oil products, natural gas, coal etc.
2. Renewable energy systems: There are different kinds of renewable energy systems but between these, only solar energy (in solar-thermal systems) is used directly and without first being changed into another energy carrier for heating. In these systems, the solar energy is absorbed by collectors, changes to heat and the heat is transferred from collector to medium.

In electricity systems, if the electricity is supplied by renewable energies this system is a renewable energy system and if supplied by fossil fuels it is a fossil fuel system. In Iran 93.3% of electricity is generated by oil and natural gas, and because changing fossil energy into electricity is inefficient, electricity systems are not sustainable and economically unsuitable for passive houses in Iran.

Because of high initial investment for renewable energy systems in Iran and the low fossil energy price, use of renewable energy systems are not economically viable. But due to the importance and benefits of renewable energies in comparison with fossil fuels, renewable energy systems must replace the fossil fuel use in passive houses in the future.

Classification of Central Heating Systems Based on the Type of Medium

Based on the type of medium there are four different central heating systems:

1. Central heating with warm water: In central heating systems with warm water, the medium is warm water (not to exceed 90°C) and the pressure is close to atmospheric pressure.
2. Central heating with hot water: Central heating with hot water is used in large installation systems. The water temperature in this system will be up to 200°C and the pressure is more than atmospheric pressure.
3. Central heating with water steam: Water steam has a much greater heating capacity. Therefore, water steam systems are used for very cold climates, regional central heating, heating of skyscrapers and other such buildings in which water steam has other uses (such as in hospitals).
4. Central heating with warm air: In warm air systems, the air is heated in warm-air furnace.

From the viewpoint of transfer of medium in the system, there are two types of systems: Systems in which the medium is transferred naturally via thermosiphon properties and systems with forced medium transfer via a pump or fan. The medium can be transferred naturally with thermosiphon property only in small systems in small buildings.

Heated air can also be naturally distributed in indoor spaces in some systems such as in radiators, convectors, etc. or fan forced such as in fan-coil system.

Cooling Systems

Classification of Cooling Systems Based on Cooling Medium

Based on the type of cooling medium there are two different cooling systems:

1. Refrigeration System: In a refrigeration system, the cooling medium circulates in the chiller, Direct Expansion (DX) or Heat Pump and the heat transfer occurs with via distillation and condensation. In the central chiller system, the medium is chilled water. In DX and Heat Pump systems, the cooling medium directly conveys the chill to the conditioned space via the evaporator and thus the cooling medium is the same medium used in the heat pump or DX system.
2. Evaporative System: In an evaporative system, the cooling is done with humidification. It is an adiabatic process. One example of these systems is an evaporative cooler. The water added to the moving air absorbs latent heat for evaporation from the air and thus cools it. The wet bulb temperature of the air does not change. This system can be used when outdoor dew point design temperature is less than indoor dry bulb design temperature and it occurs when the air humidity is low.

Heat Pump

"A heat pump system is a refrigeration cycle which by design and control moves heat in either direction" (Carrier Air Conditioning Company 1965, pp. 9-12) and can be used both for heating and cooling purposes. Heat pumps move heat energy from one place to another and from a lower to a higher temperature. Heat is removed from the source and is discharged elsewhere (the sink). In heating applications, heat is removed from ambient air, or water, soil or bedrock and delivered to where it is needed. In cooling applications, the reverse happens and heat is removed, to be discharged to the ambient air, water, soil or rock (UK Heat Pump Network, 10.05.2008).

A heat pump is, in effect, a heat engine working in reverse. A heat engine takes high-grade heat, converts it into work and rejects the energy balance at a lower temperature than the source heat. A heat pump takes waste heat, applies work to the operating fluid and provides heat at a higher temperature than the waste heat source (CAENZ 1996, p. 373).

A heat pump works by driving a working fluid around a refrigeration circuit containing four elements; evaporator, compressor, condenser and expansion valve.
The working fluid changes from liquid to gas (evaporates) as heat is absorbed from the heat source. Later in the cycle, the working fluid condenses to liquid as heat is released to where it is needed. A heat pump can be used for cooling with the addition of a reversing valve that reverses the direction of the working fluid and consequently the direction of the heat transfer. The central component of the heat pump is the compressor. This is usually driven by an electric motor, although gas engine driven compressors are also available (UK Heat Pump Network, 10.05.2008).

There are three kinds of heat pumps including "air-source", "water-source" and "ground-source" heat pumps. An "air-source" heat pump, the most common, extracts heat from the outdoor air, a "water-source" heat pump extracts heat from underground water, and a "ground-source" heat pump extracts heat from the soil. A water or ground-source heat pump is more efficient than an air-source heat pump because the ground and water are relatively constant in temperature, even when the air temperature is extremely cold or hot, and are closer to desired indoor temperatures (Laurence et al. 1999, pp.299-300).

Choosing an Appropriate HVAC System for Passive Houses of Iran

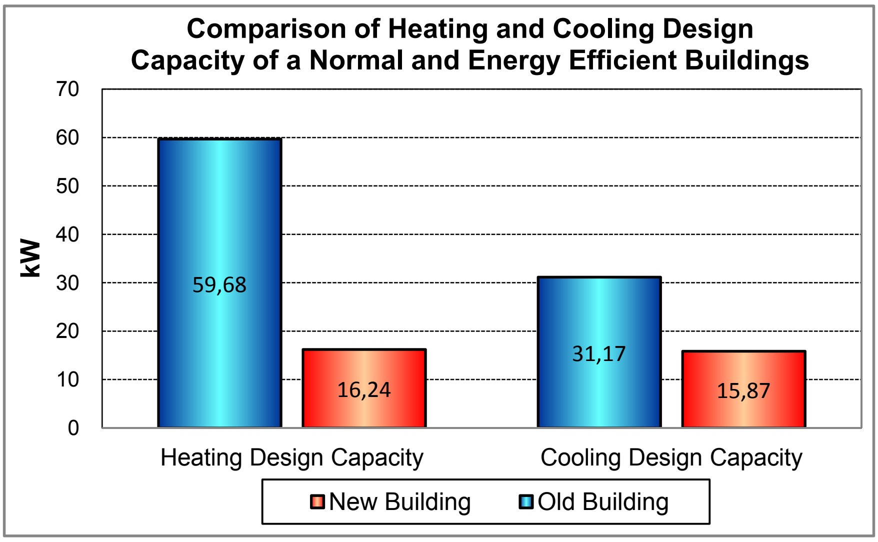
The following aspects are fundamental diagnoses that should be considered for selection of an air conditioning system.

1. Investor's financial capacity and the investment objective.
2. Space or building (purpose, location, orientation and shape)

3. Coincidental occurrence in external environment of temperature, humidity, wind, exposure to sun or other heat exchanges, and shade
4. Diversity of internal loads
5. Capability for storage of heat gains
6. Necessity and capacity for pre-cooling
7. Physical aspects of space or building to accommodate
8. Customer's concept of environment desired (Carrier Air Conditioning Company 1965, pp.9-1,9-2).

Because this HVAC system is selected to be utilised in housing used by the general population, (who generally have not got a large financial capacity), the economic aspect plays a big role and the system must be as cheap and economical as possible.

Another important characteristic when choosing a HVAC system for passive houses is their low heating and cooling energy capacity (in comparison with normal houses). Because the heating and cooling systems are used to compensate the thermal heat loss of buildings, the amount of thermal loss must be calculated in order to estimate the capacity of heating and cooling systems. The heating and cooling energy demand of a typical building and an example of a passive house are calculated in the climatic conditions of Tabriz through simulation with DesignBuilder. The heating and cooling design capacity of the passive house is respectively 72.7% (heating) and 49% (cooling) less than a typical house. However, its annual energy consumption is about 92% less than the available simulated building. The following graph compares the heating and cooling design capacity of the passive and typical house.



Source of Weather Data: U.S. Department of Energy 14.01.2008b

Based on the psychrometric chart of Tabriz, evaporative cooling is useful and effective in this city. The following figure shows the psychrometric chart of Tabriz with the comfort zone (area 1) and the area where direct evaporative cooling is effective (area 5). Based on the analysis of the psychrometric chart of

Tabriz direct evaporative cooling can be used for about 1469 hours in a year (16.8% of the year) and only 71 hours in a year (0.8% of the year) conventional air conditioning is required, which is very low and can be disregarded.

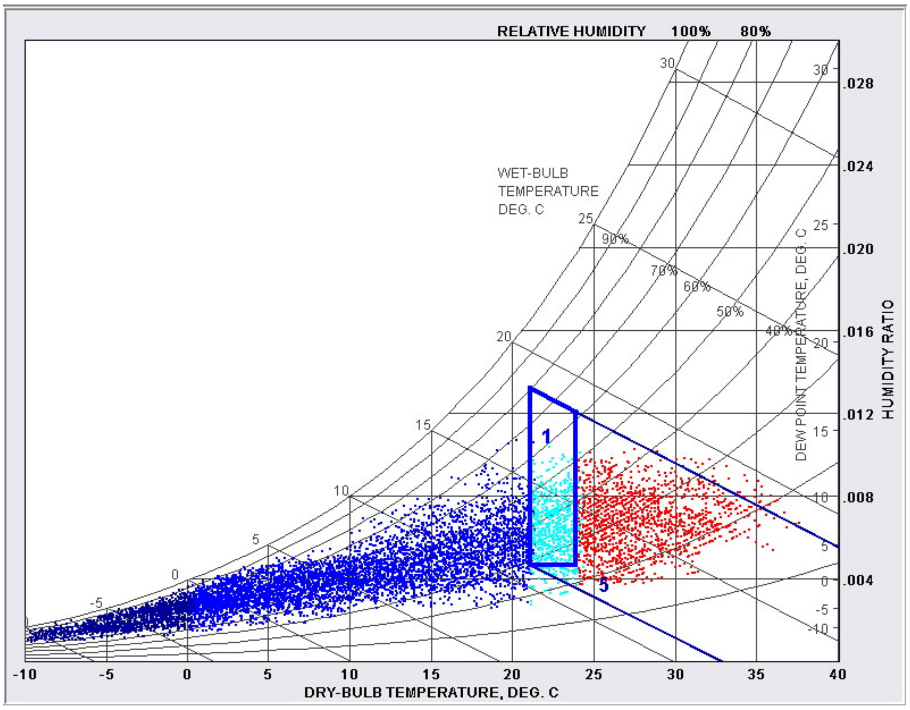


Figure 105: Psychrometric chart of Tabriz, comfort zone, and the zone of effectiveness of evaporative cooling, Source of Weather Data: U.S. Department of Energy 14.01.2008b

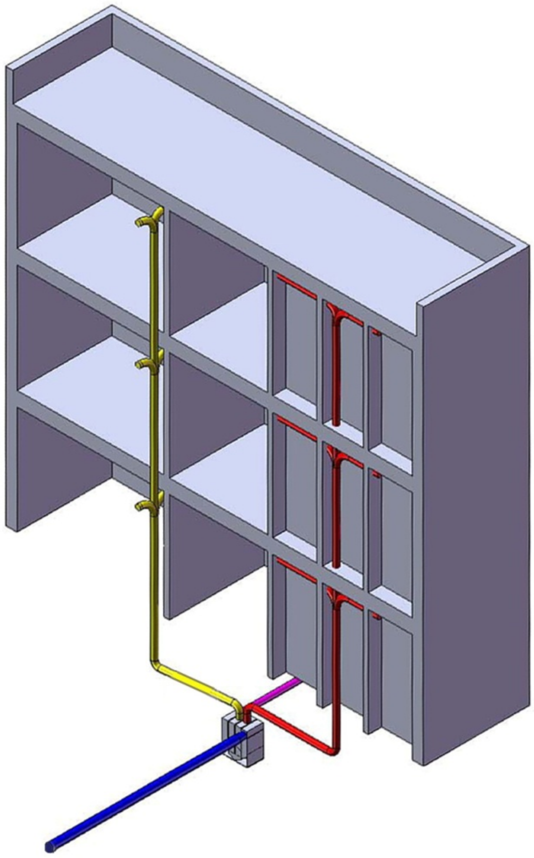
On account of low initial and operation costs of this system in comparison with refrigeration systems, evaporative cooling is a suitable system for passive houses in Tabriz. However, all cooling systems can generally be used in passive houses.

Ventilation System

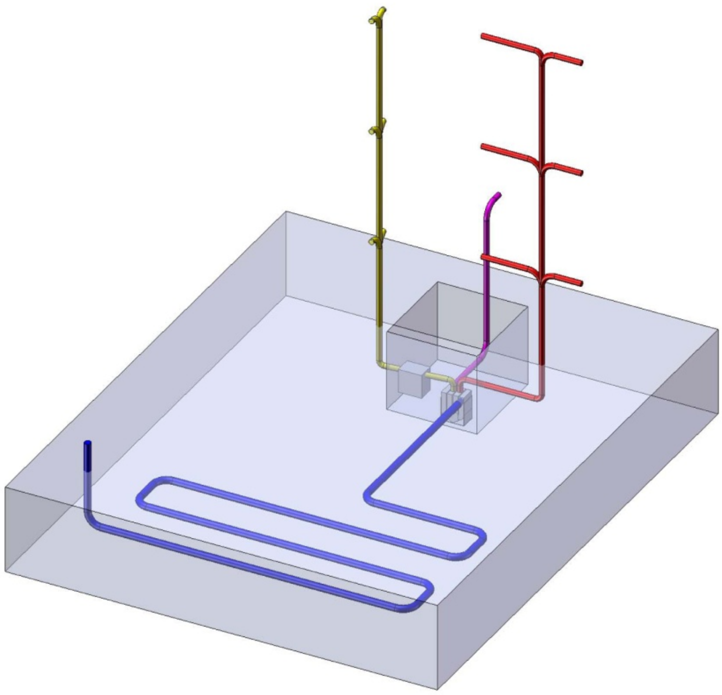
Air conditioning systems are generally divided into four basic types determined by the method through which the final within-the-space cooling and heating is attained. The basic types of air conditioning system are Direct expansion, All-water, All-air, Air-water and Heat pump (Carrier Air Conditioning Company 1965, p.9-6).

Heating energy of a house can be lost via infiltration and thus the external envelope of a house has to be airtight. In airtight buildings the reasonable indoor air quality can not be supplied with the air change from infiltration, therefore a mechanical ventilation system must be used for air change of a building. With this system, indoor warm air will be changed with outdoor cold air (in winter and the reverse in summer) and thus a significant amount of energy must be consumed in order to increase the temperature of cold outdoor air to indoor warm air in winter. If the heat of exhaust air is used for heating the fresh air with the use of an air-to-air heat exchanger, it can effectively reduce heat loss of building through air exchange. Therefore, a ventilation system with a heat exchanger, which is used in passive houses, will be used in these buildings. Fresh air will be supplied to the living, working and sleeping spaces and the used air will be extracted from the kitchen, bathrooms etc. and the heat exchanger will use the heat from the outgoing (extracted air) to warm the incoming (fresh air).

Another element of passive houses which reduces energy consumption of buildings by preheating and pre-cooling incoming air is a subsoil heat exchanger, which can also be used in these buildings.



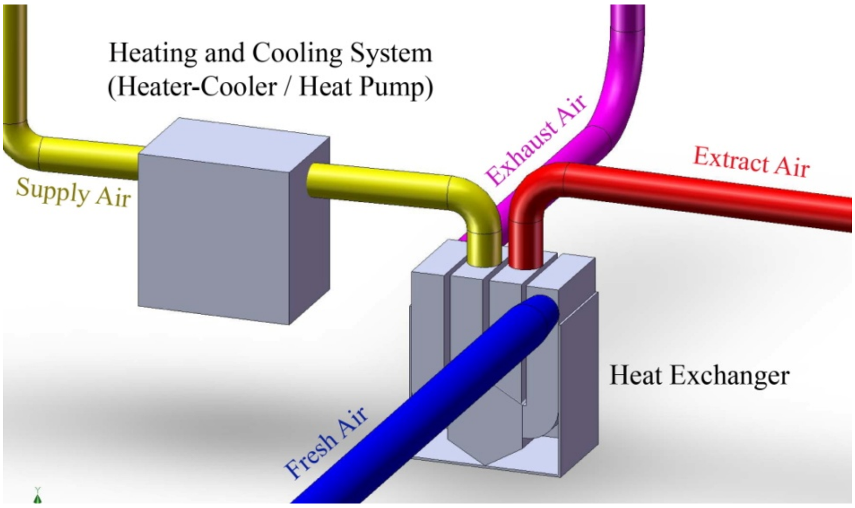
Mechanical ventilation systems are a key element of these houses, and because the air is transferred from outdoor climate to an indoor climate almost all through the year, this air can be used as a medium for heating and cooling. Therefore, all-air systems are suitable systems for these buildings, and air is used for transferring heating and cooling into the spaces. On the other hand, with attention to economic aspects, and the low heating capacity of these buildings, heating with warm air is a suitable heating system. Due to the use of air as the medium of the system used for heating the passive houses in Iran, the heat transfer in the system and heat distribution in spaces must be forced with the use of a fan.



Both heating and cooling systems can be integrated with the ventilation system of these buildings. Heat pumps can be used both for heating and cooling purposes and can be integrated in an all-time ventilation system in order to supply heating and cooling requirements. Another heating system which can be used for is a warm-air furnace which effectively matches the ventilation system of these buildings and makes a central heating system with warm air. In this case, evaporative cooling integrated in the ventilation system can also be used for cooling the buildings. Because of the low efficiency of heater-cooler systems at humidifying and dehumidifying, it is sometimes not included as an air conditioning system, however, this system is a suitable all-air system for passive houses of Iran, (in which the heating is done with a warm air furnace and the cooling is done with an evaporative cooler).

Results

Two systems are suitable HVAC systems for passive houses of Iran. These two systems are Heater-Cooler system and ventilation system with Heat Pump for generating heating and cooling. Both mechanical equipments used for heating and cooling, that is, (1) heat pump and (2) warm-air-furnace plus evaporative cooler should be located in the supply air canal of ventilation system after the heat exchanger.



Heater-Cooler System

In Iran, because of four reasons, the warm-air-furnace can be used as a heating system for passive houses: low heating energy loads, low heating design capacity, inevitability of mechanical ventilation system, possibility of air use as a heating vehicle. Central Warm-Air Furnace is a type of space-heating equipment where a central combustor or resistance unit -generally using gas, fuel, oil, or electricity- provides warm air through ducts leading to the various rooms (Laurence et al. 1999, p.293). There are two types of Central Warm-Air Furnaces including forced-air furnaces and gravity furnace.

On the other hand, evaporation cooling is very effective in Tabriz and therefore active (or hybrid) evaporation cooling can be used by using the ventilation system as part of the evaporative cooling system. Spraying of water or use of a wet material (straw, fabric, bamboo, etc.) in the ventilation system will constitute the evaporative cooling system.

The composition of ventilation systems of passive houses, warm-air-furnace as heating system, and hybrid evaporation cooling will result in a Heater-Cooler system as an HVAC system of passive houses in Iran. The heater-cooler system suits the climatic condition of Tabriz based on the psychrometric chart (and building bioclimatic chart) of the area and can thus supply appropriate heating and cooling conditions. It is also suitable in that it is a cheap system and has minimal initial and operation costs. Therefore, heater-cooler system is a suitable system for passive houses of Tabriz.

According to heating capacity of 13966.4kcal/hr (16.24kW) and volume of controlled spaces of building, the heating capacity of the heater-cooler must be 20000kcal/hr (burner) and the ventilating (airing) capacity of system must be 7000CFM (11830m^3/hr).

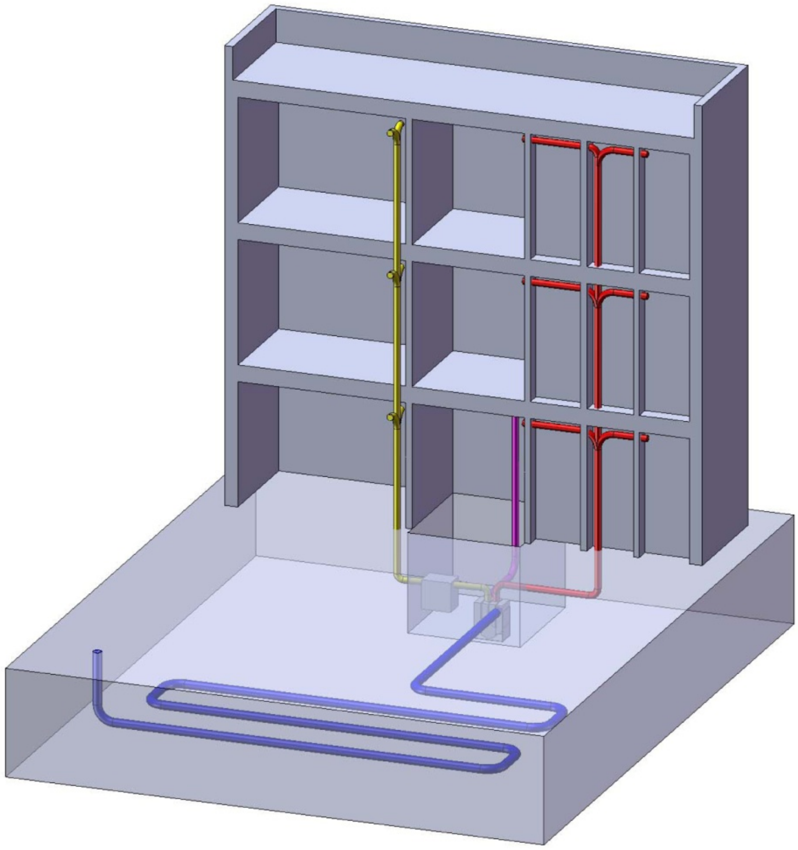
Heat Pump System

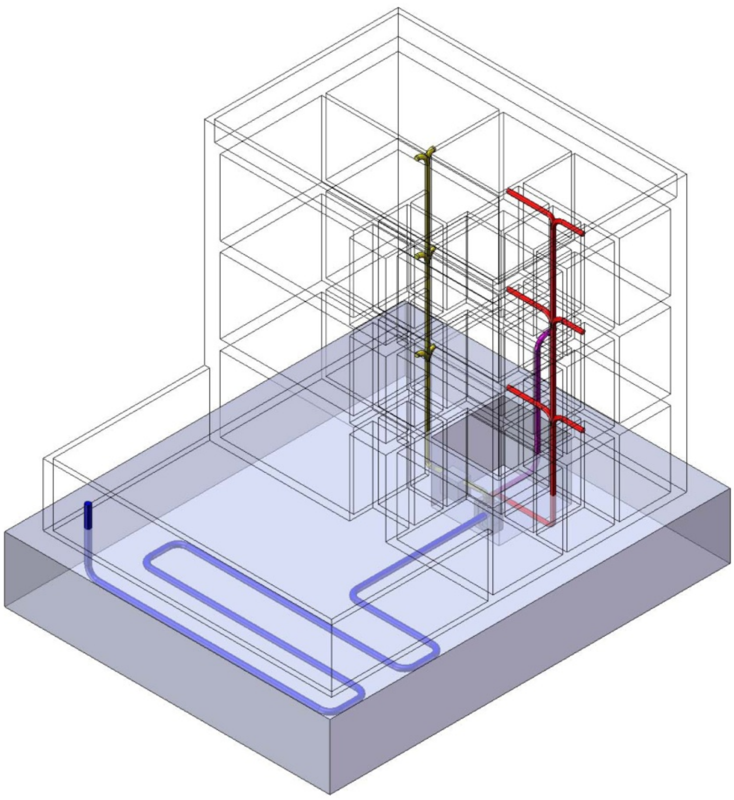
Heat pumps provide both heating and cooling services and thus they suit for passive houses of Iran, which need both heating and cooling. For example, ground-source heat pumps can be used for this purpose. They use the earth or ground water (or both) as the source of heat in the winter, and as the “sink” for the heat removed from the home in the summer. There are two kinds of heat pumps which include electricity heat pumps and gas heat pumps. Apart from rare cases, (where heat rejection from a required refrigerating system can be utilized) it has proved very difficult to market [electricity] heat pumps without government subsidy (Pearson 2004, p.16). On the other hand, the electricity is generated in Iran from fossil fuels and has a higher price in comparison with natural gas. Therefore, electricity heat pumps are not suitable for passive houses of Iran.

Although heat pumps that consume natural gas are not as popular in Iran as electricity heat pumps, they are suitable systems for the heating and cooling of Iran's passive houses.

According to the heating and cooling design capacity of the example energy efficient building, which is respectively 4.168RT[1] (16.24kW) and 4.153RT (15.87kW), a gas heat pump with 5RT capacity can be used as both heating and cooling equipment for this house. This heat pump with the above mentioned capacity is available and used in Iran.

[1] - Refrigeration ton.





Chapter Five: Conclusion and Recommendation

Conclusion

Due to the shortage of existing fossil fuel resources, the worldwide population increase, continually increasing energy costs, and problems caused by fossil energy consumption, the worldwide energy consumption must be reduced. Iran's energy consumption, while already high, increases year by year. About 97% of the total energy consumption and 98.8% of the energy consumption of buildings in Iran is supplied from fossil energies. Renewable energies are not practically nor extensively used in Iran. High fossil energy consumption in Iran has also caused high levels of air pollution in some of the big cities, and especially in Tehran.

The buildings in Iran have high energy consumption. More than 40% of the total energy is consumed in residential and commercial buildings. Iran's cold climatic region is extensive and consumes significant amounts of energy, especially for heating. Due to its climatic conditions, however, this region has a high potential for energy saving in buildings.

As a result of low energy costs through excessive energy subsidies, high construction material costs, and the general economic conditions in Iran, energy saving in buildings through expensive methods is not economically viable. Thus, there is no social interest in energy saving, especially with measures that increase the building costs, such as the use of insulation material, insulated windows, active solar systems, etc.

For the situation in Iran, with low energy prices and high construction costs, the use of cost-neutral or cheap energy saving methods (especially architectural methods) is very important. Architectural methods rarely increase the building costs and are only achievable though proper design.

No research has been done regarding architectural energy saving in Iran's cold climatic region, nor passive houses (especially those which lead to practical and usable results in Iran). Present work is aimed at filling the absence of research, leading to economically and technologically suitable and practical results for Iran's situation.

The main purpose of this study was:

- to find suitable types of climate and energy responsive buildings for the cold climatic region of Iran,
- to test the suitability of passive houses for this region, and finally
- to investigate architectural factors that reduce the energy consumption of buildings in this climate in order to achieve cost efficient and energy efficient buildings.

The present research indicates that passive houses are climatically suitable for Iran's cold region. Its passive houses, however, need additional cooling systems. The original type of German passive house is not economically nor technologically suitable for Iran due to significant differences in these fields between Iran and Germany.

This research also proves that architectural design basically affects heating, cooling and the total energy consumption of buildings. Its effect varies according to the specific climate and is very high in climates with a high temperature range, low relative humidity, high solar radiation, low cloudiness index, etc. such as Iran's cold climatic region. Energy saving through architectural design is emission-free, cheap, easy to achieve and is especially important for countries with low energy costs such as Iran, in which energy saving through active systems and even the use of high-tech materials (insulation material, multiple layer windows, etc.) is not economically viable.

The potential of architectural energy saving in Iran's cold climatic region is about 64%. It increases, however, by increasing the U-value of the thermal envelope. In this region, with the city of Tabriz as the case study, the energy consumption of simulated buildings is reduced 64% through architectural design alone.

Technological Evaluation

The energy efficient buildings in Iran can be built by conventional materials, which are widely used today for construction. Among all materials and components needed by passive houses, only the method of heat recovery of waste air via air-to-air heat exchangers is not locally produced in Iran and must either be developed as a local product or imported from other countries. However, as a simple solution, it is possible to use two concentric pipes with different diameters (one inside the other), where the supply air flows through the inner pipe and the exhaust air flows in the annular space between pipes in the opposite direction. This system (a hand-made air-to-air double-pipe heat exchanger) has lower efficiency but it is much cheaper than other heat exchanger devices. Alternatively, there is the possibility of using adiabatic cooling by spraying water in the exhaust air of the annular space between pipes for cooling purposes in summer.

Gas heat pumps make due system for heating and cooling passive houses in Iran, and heater-cooler unit systems are particularly ideal in this country.

As a general rule, all materials, facilities, and equipment needed for energy efficient or passive houses are either available in Iran or can be imported in rare cases. The most important aspect for the utilisation of different systems, and building materials and components is their economic efficiency.

Economic Evaluation

Because construction materials in Iran are expensive and houses are generally built without insulation material, with single glazed windows, etc., there is a high difference in construction costs (about 50%) between passive and non-passive houses. Nonetheless, if the passive houses have an energy efficient architectural design (based on the recommended factors for reducing energy consumption of buildings in cold climates), the use of these buildings is economically viable when based on international energy costs. Investment for such buildings has a very short payback time (5.6 years) and very high internal interest rates (36.6%). However, investments for passive houses with the subsidized, low energy costs of Iran are not economically viable.

Therefore, although investment for passive houses is to the benefit of to the national capital in Iran, due to the highly subsidized energy in Iran, there is no high public demand for such projects, unless they are financially supported by the government.

General energy saving, and also that of buildings, will not effectively occur in Iran until it is economically viable. It is not likely to occur without government intervention of some kind, either by reduction or elimination of fossil fuel subsidies or by the establishments of subsidies for energy saving measures such as insulation material, insulated (multi layer) windows, etc.

Energy prices are continually increasing. On the other hand, "the substantial subsidies provided for fuel in Iran place a burden on the fiscal budget and introduce serious distortions into the economy. For these reasons, the government may want to continue eliminating these subsidies" (Sarbib et al. 2001a, p.vii). Therefore, energy saving in buildings would become increasingly more cost effective and the social interest for energy saving projects and energy efficient buildings would increase.

Results

The main outcomes of this research, which are based on different simulations and analyses, can be summarized in the following different categories:

- Increasing the thermal resistance of components of the thermal envelope, decreasing thermal bridges, and increasing the airtightness and compactness of buildings achieves a reduction of thermal losses. Increasing the thermal resistance of the envelope also increases the ambient radiative and operative temperatures, thus causing a comfortable indoor climate with lower air temperature (decreasing preferred winter indoor air temperature) and increasing thermal comfort. Therefore, insulation of walls, roofs and floors, the use of multiple glazing windows with insulated frames, and the use of insulated external doors, etc. effectively decreases the energy consumption of buildings.

- The energy efficient houses and passive houses in Iran can be built with conventional construction materials available such as brick. A thin brick wall of 10.5cm, when insulated, is the optimum case in different aspects for constructing energy efficient buildings. In such walls, solid bricks are more effective than hollow clay tiles due to their higher thermal mass.

- An architecturally well designed, three-story passive house in Iran needs only about 17cm wall and roof insulation material. On the other hand, construction of passive houses with double glazed windows is also possible for Iran. However, a passive house with double glazed windows needs much more insulation material than a passive house with triple glazed windows to achieve a similar performance.

- From the point of view of energy efficiency, flat roofs are more effective than pitched or curved roofs. Locating a pitched roof over the flat roof (non-residential attic) for economical reasons is not recommended. However, it leads to a very small reduction in the energy consumption of a building.

- Use of a highly efficient air-to-air heat exchanger for supplying the whole fresh air to a building effectively reduces the heat loss through air change by re-covering the heat from exhaust air and applying it to supply air. Mechanical ven-tilation without passing through the heat exchanger increases both total energy consumption and design capacity of a HVAC system.

- Different suitable passive heating and cooling methods can be integrated in energy efficient buildings of Iran in order more effectively to reduce their energy consumption.

Windows

- Between all components of a building's thermal envelope, windows are the most important. They affect the energy consumption of buildings because they generally have much less thermal resistance in comparison with other compo-nents but also receive solar heat, causing heat gain. Due to the importance of so-lar heat gain through windows, the correct placement and area of windows in dif-ferent orientations is a very important factor. This is especially true for Iran's cold climatic region in which, for example in the city of Tabriz, at least 25% of the yearly passive solar direct gain is required. The U-value of windows is also a very important factor in order to reduce their heat loss.

- Results of present research show that if the building has the same triple glazed window ratio in all orientations with external blinds, the optimal window ratio (in all orientations) is 40%, but with internal shading devices or with no shading devices, the most efficient window ratio is 30%.

- In a building with the same double glazed window ratio in all orientations and external blinds, the optimal window ratio (in all orientations) is 30%.

- In the case of using triple glazed windows with external shading devices in only an east, west or south orientation, an increase in window area reduces the building's total energy demand. This is most effective for south-facing windows. Therefore, if a building can have windows in only one of the above mentioned orientations, from the viewpoint of energy efficiency it is best to maximise this window area. North-facing windows increase both heating and cooling energy consumption under all conditions and thus must be minimised.

Shading Devices

- Windows must maximise solar heat gain during the heating period and minimise it during the cooling period. Therefore, shading devices are very im-portant components in Iran's cold climatic region, where (in Tabriz, for example) shading is needed for 14.9% of the year. Because of high levels of direct solar radiation, shadings have a very significant effect on energy consumption of buildings in Iran. Proper shadings with individual operation for every orientation can effectively decrease the energy consumption of buildings.

- External shading devices are generally much more effective than internal shading devices. Most effective are the adjustable and movable external shading devices. Among all varieties, external blinds are very effective in reducing energy demand. However, overhangs with the optimum dimension for south-facing windows are also very effective, even for windows which have external blinds.

- If adjustable external shading devices of windows and skylights are controlled based on heating and cooling demand, they effectively decrease the cooling energy consumption and prevent any significant increase in heating energy consumption. Therefore, the use of proper adjustable (and suitably controlled) shading devices has a very positive effect on the energy demand. Due to the importance of controlling the shading devices, automatic control is the best option.

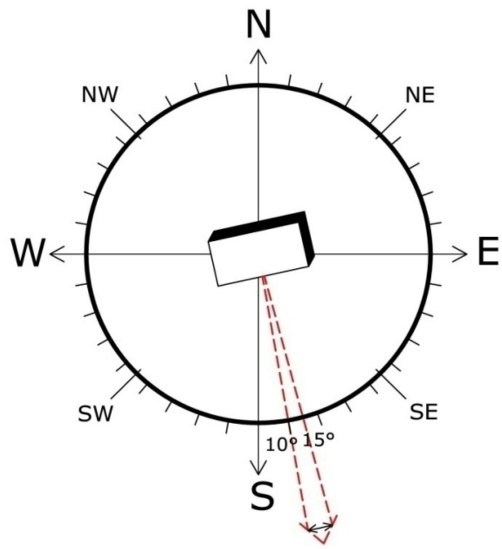
- Increasing the depth of overhang and louvre projection for south-facing windows is effective up to a certain width, and must therefore be calculated with regard to climate and the window height.

- Large and unsuitable shading devices or the use of multiple shading devices for one window increases the total energy consumption but decreases the cooling energy demand.

Results of Simulation

The architectural factors that reduce the energy consumption of buildings in Iran's cold climatic region are briefly stated as follows. These factors are the results of several simulations carried out throughout the research. These factors can generally be used in all houses of Iran's cold climatic region to reduce their energy consumption or can be used in passive houses to effectively reduce the insulation requirements and their costs.

- Orientation of building 10-15° east of south
- Having suitable elongation (optimum ratio of south side to east side is between 1 and 2 for the building and between 0.6 and 1.2 for the site)
- Increasing the amount of south-facing windows to 100%
- Decreasing the north-facing windows (in all conditions) to 0%
- Decreasing the east and west-facing windows to 0% for buildings with a large area of south-facing windows
- Increasing the east and west-facing windows up to 100% for buildings with no south-facing windows



- Avoiding the use of skylights without shading devices and with internal blinds (in the pitched roofs of residential and non-residential attics)
- Decreasing the area of external doors
- Use of thermal buffer zones for external doors
- Avoiding placement of uncontrolled spaces and unimportant spaces (staircase, bathroom, WC, Garage, etc.) to the south
- Placement of living rooms, which are used during the day, to the south
- The following table gives recommendations for room exposures for residential buildings in cold climates.

Tabe 39: Suggested sun orientation for rooms

	North	East	South	West
Bedroom	●	●		●
Living Room			●	
Dining Room	●	●		●
Kitchen	●	●		●
Library	●			
Bathrooms		●		●
WC	●	●		●
Utility	●			
Garage	●	●		●
Workshop	●			
Staircase	●			
Guest room	●	●		●

- Increasing the number of stories of buildings (three or four stories are appropriate for low rise buildings)
- Compactness of building form
- Decreasing the area of external walls of the thermal envelope
- Increasing the area of common walls with neighbouring buildings, especially walls of controlled spaces
- Increasing the common area of thermal envelope with ground (locating a part of the building under ground level)
- Decreasing the height of the constructed nonresidential platform of the building (locating the building on the ground level)
- Use of proper shading devices for skylights and windows of every orientation
- Use of external shading devices (the most effective of which is external blinds).
- Controlling the movable shading devices according to cooling and heating energy demand
- Closing the adjustable shading devices during winter nights
- Opening the shading devices during summer nights
- Use of overhangs with the optimum dimension for south-facing windows

- Avoiding the use of unsuitable shading devices (for example, fins for south-facing windows)
- Avoiding the use of external closed blinds or those which are not controlled according to heating and cooling energy requirements
- Shading of windows, roof and courtyard in summer with vegetation
- Use of Vegetation and water pools in courtyards (for natural evaporative cooling in summer)
- Spraying of water at the floor of a courtyard in summer
- Opening of apertures during summer nights (for night cooling by thermal mass)

The following factors reduce the energy consumption and insulation requirements of passive houses in Iran's cold climatic region:

- Use of subsoil heat exchangers at a depth of 4m for pre-heating and pre-cooling of the fresh air supply, except in April, May and June
- Use of equal thicknesses of wall and roof insulation to reduce the total amount of required insulation material (decreasing the difference in the thickness between wall and roof insulation decreases the total insulation material)

Recommendations

Recommendations to the Government and Energy Authorities

Some recommendations as to the energy responsive policies are in the following:

- Reduction or elimination of energy subsidy (increasing the energy costs)
- Subsidisation of energy saving materials such as insulation material, insulated windows, shading devices, etc.
- Financial support, facilities, gratuitous technical and professional consulting, etc. for energy saving methods and construction of energy efficient buildings in order to increase public recognition and popularity.
- Introduction of new, enforced building energy regulations
- Improvement of the city's microclimate by creating more water bodies and green spaces (vegetation)
- Heed of governmental energy saving organizations to energy saving and energy conservation in buildings
- Introduction of new regulations for urban planning and neighbourhood design. Adaptation of site division to the urban climate (urban design and division of an area into smaller lots must be done so that the building sites are oriented toward the south (or 10-15° east of south) and have proper elongation from the viewpoint of energy efficiency)

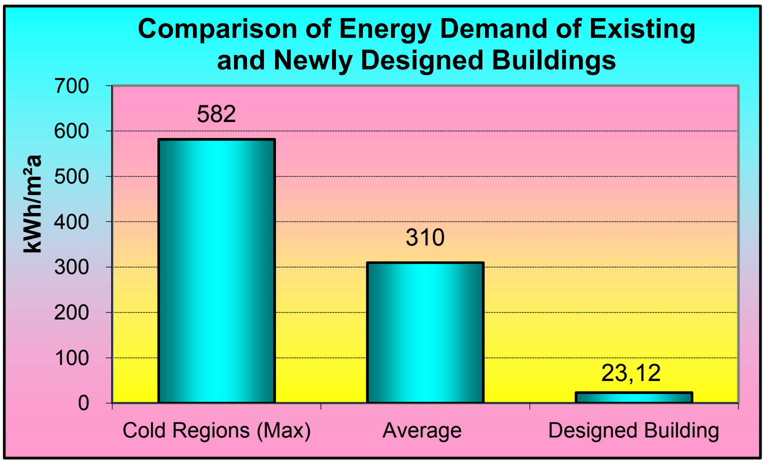
Recommendations to the Researchers

For constructing buildings that are more responsive to energy in Iran, researches can be like in the following:

- There is a lack of information about comfort zone criteria especially for certain climatic regions in Iran. In addition, winter comfort zone borders in Iran are higher than in other countries. Therefore, research in this area is much significant.
- Decreasing the low temperature border of the comfort zone and the heating set-point temperature by introducing regulations
- Doing practical and usable research which can be directly applied to energy conservation. Practical use of theoretical research results about energy saving in buildings.
- Doing research (e.g. further PhD works) about building energy efficiency and architectural energy saving in other climatic regions of Iran, especially warm and dry as well as warm and humid climates.
- Research on energy efficient and climate responsive urban design and adapting neighbourhoods to climates (urban planning and urbanism).

Discussion

The following diagram compares the energy consumption of buildings in Iran[1] with that of a newly energy efficient well designed building[2]. Though this building is located in Iran's cold region (Tabriz), its energy demand is less than 4% that of the existing buildings in the same climate and less than 7.5% of the average energy demand of buildings in Iran. It shows the high capacity of energy saving in buildings of Iran's cold climatic region, related to both architectural measures and use of insulation material.



[1] - According to Iranian fuel conservation organization (2005a, p.1) building energy consumption in Iran is 582kWh/m²a for cold regions and an average of 310kWh/m²a.,

[2] - The newly well designed building with 11.8cm wall and roof insulation material and triple glazed windows has only 23.12kWh/m²a energy consumption.

The results of present research can generally be applied to the buildings of other cities of Iran's cold climatic region. However, for more accurate and detailed recommendations, the results must first be tested in other cities.

Because of their lower latitude in relation to Tabriz, most other cities of Iran's cold climatic region have higher solar radiation. Therefore, the energy saving rules in the buildings mentioned in this treatise will generally be even more effective in these other cities of Iran's cold climatic region. Architectural energy saving would be more effective and more easily achievable in other cities than in Tabriz.

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Appendix

Climate

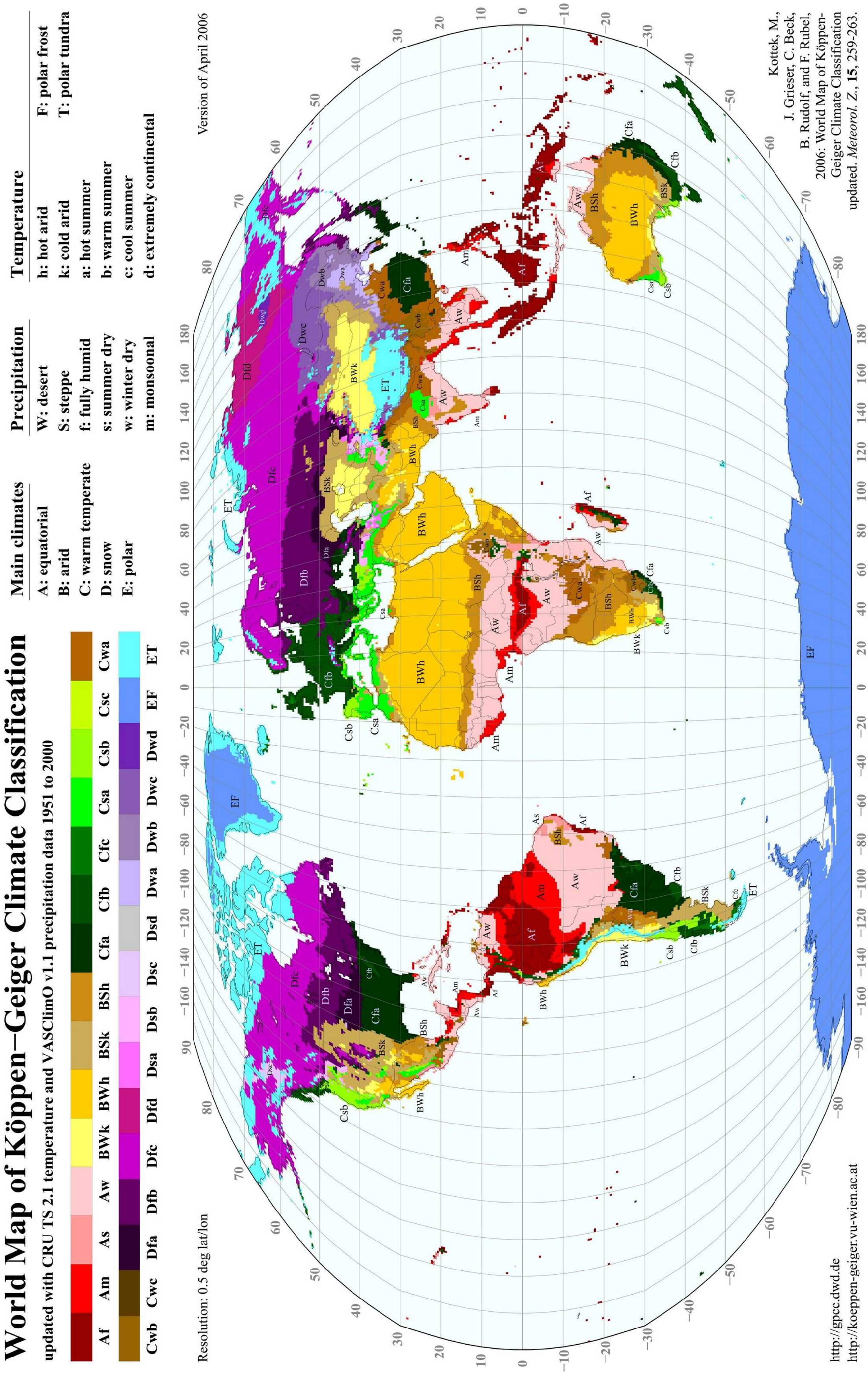


Table 40: Köppen climate classification

A	Tropical humid	Af	Tropical wet	No dry season
		Am	Tropical monsoonal	Short dry season; heavy monsoonal rains in other months
		Aw	Tropical savanna	Winter dry season
B	Dry	BWh	Subtropical desert	Low-latitude desert
		BSh	Subtropical steppe	Low-latitude dry
		BWk	Mid-latitude desert	Mid-latitude desert
		BSk	Mid-latitude steppe	Mid-latitude dry
C	Mild Mid-Latitude	Csa	Mediterranean	Mild with dry, hot summer
		Csb	Mediterranean	Mild with dry, warm summer
		Cfa	Humid subtropical	Mild with no dry season, hot summer
		Cwa	Humid subtropical	Mild with dry winter, hot summer
		Cfb	Marine west coast	Mild with no dry season, warm summer
		Cfc	Marine west coast	Mild with no dry season, cool summer
D	Severe Mid-Latitude	Dfa	Humid continental	Humid with severe winter, no dry season, hot summer
		Dfb	Humid continental	Humid with severe winter, no dry season, warm summer
		Dwa	Humid continental	Humid with severe, dry winter, hot summer
		Dwb	Humid continental	Humid with severe, dry winter, warm summer
		Dfc	Subarctic	Severe winter, no dry season, cool summer
		Dfd	Subarctic	Severe, very cold winter, no dry season, cool summer
		Dwc	Subarctic	Severe, dry winter, cool summer
		Dwd	Subarctic	Severe, very cold and dry winter, cool summer
E	Polar	ET	Tundra	Polar tundra, no true summer
		EF	Ice Cap	Perennial ice

Cloudiness Index

Cloudiness index can be used for the different cities of Iran with different formulas. These formulas have been estimated with the use of the Angstrom equation of the weather clearness coefficient and climatic data. This formula is for the Tabriz:

$K_t = 0.0143 + 0.670\ S + 0.003\ T + 0.02\ R$

Where:

S: Fraction of sunny hours

T: Temperature (°C)

R: Relative humidity (%) (Bahadorinezhad and Mirhosainy 2004)

The monthly and annual average of this coefficient for Tabriz is shown in the following table:

Table 41: Average of monthly weather clearness coefficient for Tabriz, Source: Bahadorinezhad and Mirhossaini 2004

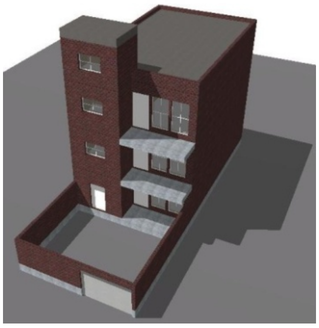
Annual average	19Feb.- 20Mar.	20Jan. -18Feb.	21Dec. - 19Jan.	21Nov.-20Dec.	22Oct. -20Nov.	22Sep.-21Oct.	22Aug.-21Sep.	22Jul. - 21Aug.	21Jun. - 21Jul.	21May. -20Jun.	20Apr.-20May.	20Mar. -19Apr.
0.57	0.47	0.48	0.41	0.47	0.57	0.64	0.68	0.70	0.68	0.64	0.56	0.50

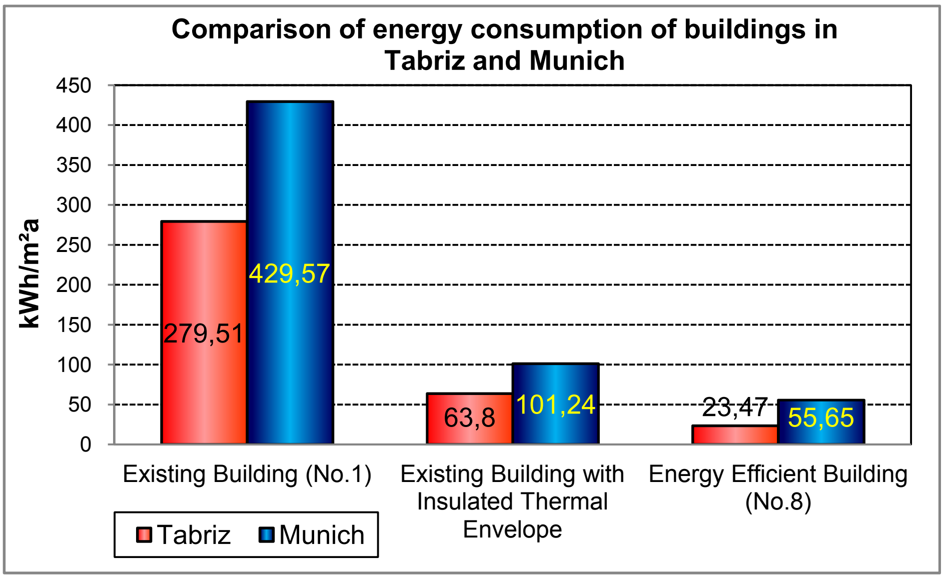
Table 42: Average climatic factors of Tabriz (1951 – 2000)

Main factor	Climatic factor		JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	Annual
Degree days	Cooling degree day		0.0	0.0	0.0	0.0	3.1	51.7	154.5	146.2	37.1	0.3	0.0	0.0	392.9
	Heating degree day		615.0	502.4	398.3	201.1	66.6	6.0	0.2	0.2	7.2	122.8	330.2	523.2	2773.2
Temperature	Ground Temperature	* 0.5 m (°C)	-0.3	-1.4	0.7	4	12.6	19.3	23.8	25.2	22.8	17.7	10.7	4.3	11.62
		* 2.0 m (°C)	4.1	2	2.4	4.2	10	15.2	19.4	21.7	21.2	18.2	13.5	8.4	11.18
		* 4.0 m (°C)	7.8	5.6	5.1	5.8	9	12.6	15.8	18.1	18.6	17.3	14.5	11.1	11.78
	Average of dry bulb temperature (°C)		-2.4	-0.3	4.9	11.1	16.4	21.8	25.6	25.3	20.9	13.8	6.3	0.5	12
	Average of Minimum temperature (°C)		-5.7	-4.1	0.3	5.9	10.5	15.2	19.2	18.9	14.3	8.2	2.1	-2.8	6.8
	Average of Maximum temperature (°C)		2.2	4.6	10.2	16.8	22.7	28.6	32.7	32.5	28.2	20.5	11.9	5	18
	Average of dew point temperature (°C)		-7	-5.9	-2.5	1.6	4.9	6.4	8.2	7.9	4.9	2.5	-0.4	-4.3	1.3
Humidity	Average of Maximum relevant humidity (%)		84	83	81	77	72	61	53	54	59	70	81	85	72
	Average of Minimum relevant humidity (%)		58	53	44	36	31	23	21	21	22	33	46	56	37
Sunshine	Solar Radiation	Direct Average (Wh/m²)	2195	4053	3335	5745	7310	7489	7210	6507	6409	5699	4701	3536	64189
		Diffuse Average (Wh/m²)	931	1294	1960	2263	2177	2299	2221	2236	1721	1356	1103	1011	20572
		Global Average (Wh/m²)	3126	5347	5295	8008	9487	9788	9431	8743	8130	7055	5804	4547	84761
	Monthly total of sunshine hours		121.6	143.1	176.4	200.6	268.7	334.3	354.2	337.1	302.3	230.9	178.3	130.2	2777.7
Cloudy	No of clear days (0-2)/8		6.8	6.5	6.8	5.9	9.8	20.8	25.0	25.9	25.0	16.1	10.9	7.9	167.4
	No of cloudy days (7-8)/8		12.8	11.1	12.0	10.9	5.8	1.1	0.3	0.3	0.4	4.3	7.3	11.5	77.8
	No of partly cloudy days (3-6)/8		11.3	10.7	12.2	13.1	15.3	8.2	5.8	4.9	4.6	10.6	11.7	11.6	120.0
Wind	Average of wind speed (Knots)		4.0	4.5	5.6	6.5	6.3	7.6	9.5	8.9	6.6	4.7	3.8	3.7	6.0
	Fastest wind direction and speed (knots)	Direction	200	120	240	360	250	230	360	90	100	250	100	210	360
		Speed	50	50	48	56	49	47	58	48	46	49	50	35	58
		Year-day	79 - 4	61 -27	63 -18	93 -22	82 -19	99 -25	92 -10	62 -25	58 -29	92 -26	59 -20	77 -13	92
	Prevailing wind direction speed (knots) and percent	Prevail. Direct.	90	90	90	90	90	90	90	90	90	90	90	90	90
		Prevail. Speed	5.8	6.0	7.2	8.1	8.0	9.7	11.4	11.1	9.8	7.4	6.3	5.9	8.7
		Prevail. Percent	23.4	19.6	18.3	17.2	19.8	30.2	45.5	44.5	30.0	21.2	17.9	19.7	25.6
		Calms percent	36.5	32.3	28.3	24.4	23.2	17.1	10.5	12.2	24.2	34.7	40.2	39.2	26.9
		Wind obser. No.	247.6	224.6	247.4	239.9	247.6	239.8	246.6	243.5	238.3	245.6	239.8	247.8	2908.5
	Vector wind direction magnitude (knots) and wind steadiness (%)	Vector direction	78	57	231	236	190	82	81	82	86	87	83	65	83
		Wind magnitude	1.2	0.4	0.2	0.9	0.2	2.5	6.5	5.9	2.6	0.8	0.5	1.0	1.7
		Steadiness (%)	30.0	8.9	3.6	13.8	3.2	32.9	68.4	66.3	39.4	17.0	13.2	27.0	28.3
Precipitation	Greatest daily of precipitation (mm)		22.0	37.0	63.0	53.0	30.0	32.0	30.0	28.0	23.0	26.0	37.0	29.2	63.0
		Year-day	67 - 7	56 - 7	77 - 3	81 -17	94-13	78 - 1	60 -21	62 - 8	66 -14	68 -25	63 -24	69 -23	77
	Monthly total of precipitation		22.8	25.0	42.3	51.0	41.9	18.0	5.7	3.5	8.2	23.7	27.9	23.3	293.3
	No of days with precipitation		10.6	10.1	13.5	13.7	13.2	6.5	2.8	1.9	2.6	7.9	8.3	9.5	100.6
	No of days with snow or sleet		9.4	8.0	5.2	1.0	0.0	0.0	0.0	0.0	0.0	0.4	1.9	6.1	32.0

Energy Consumption of Buildings in Tabriz and Munich

Table 43: Energy consumption of Existing Building (No.1), Existing Building with Insulated Thermal Envelope and Energy Efficient Building (No.8) in Tabriz and Munich

	Wall	Roof	Window	Ext. Door	Infiltration	Energy Consumption	Tabriz	Munich
	U-Value (W/m²K)				ac/h		kWh/m²a	
	2.021	0.407	6.121	2.602	1	Heating	268.10	428.70
	Existing Building (No.1)					Cooling	11.40	0.87
						Total	**279.51**	**429.57**
	0.251	0.150	0.786	2.390	0.3	Heating	59.17	101.13
	Existing Building with Insulated Thermal Envelope					Cooling	4.63	0.11
						Total	**63.80**	**101.24**
	0.251	0.150	0.786	2.390	0.3	Heating	12.13	53.59
	Energy Efficient Building (No.8)					Cooling	11.33	2.06
						Total	**23.47**	**55.65**



Atmospheric Comfort and Danger Zones

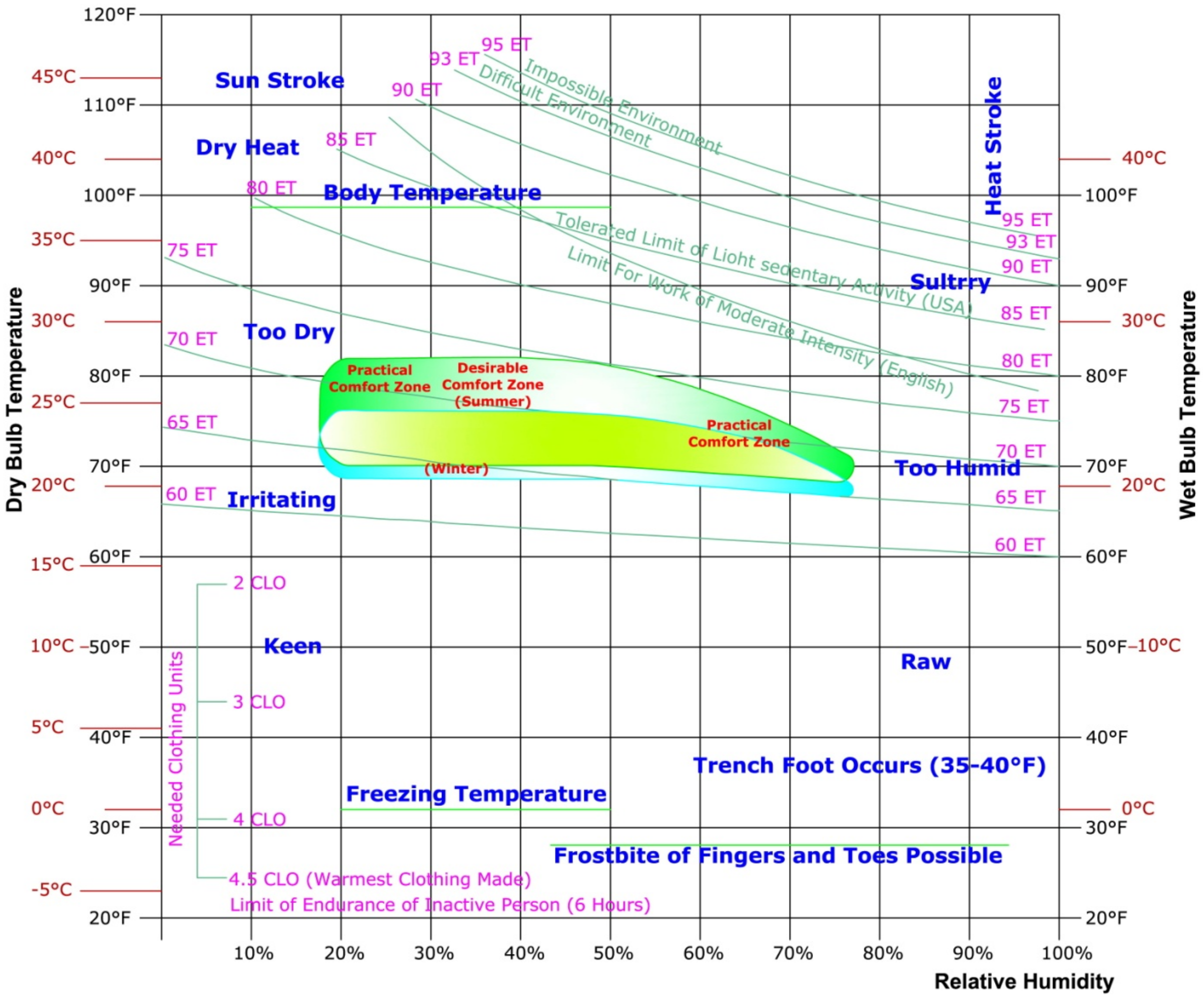
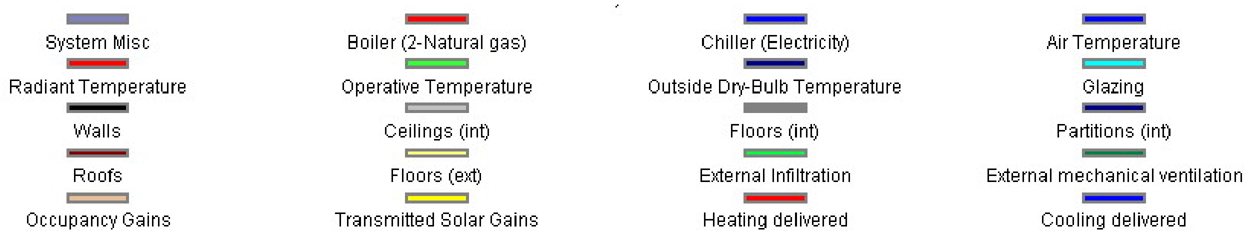


Figure 106: Atmospheric comfort and danger zones (for inhabitants of moderate climate zones), Source: Olgyay 1963, p.19 (my drawing)

Daily Graphs of Simulated Buildings

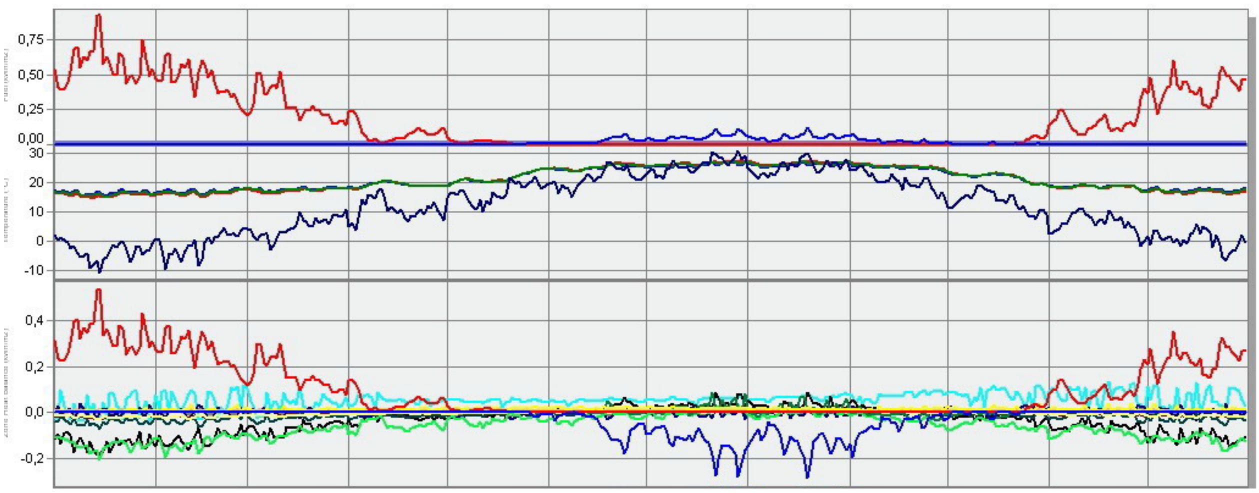
Figure 107: Daily graph of temperatures, heat gains and energy consumption of simulated buildings

Legend

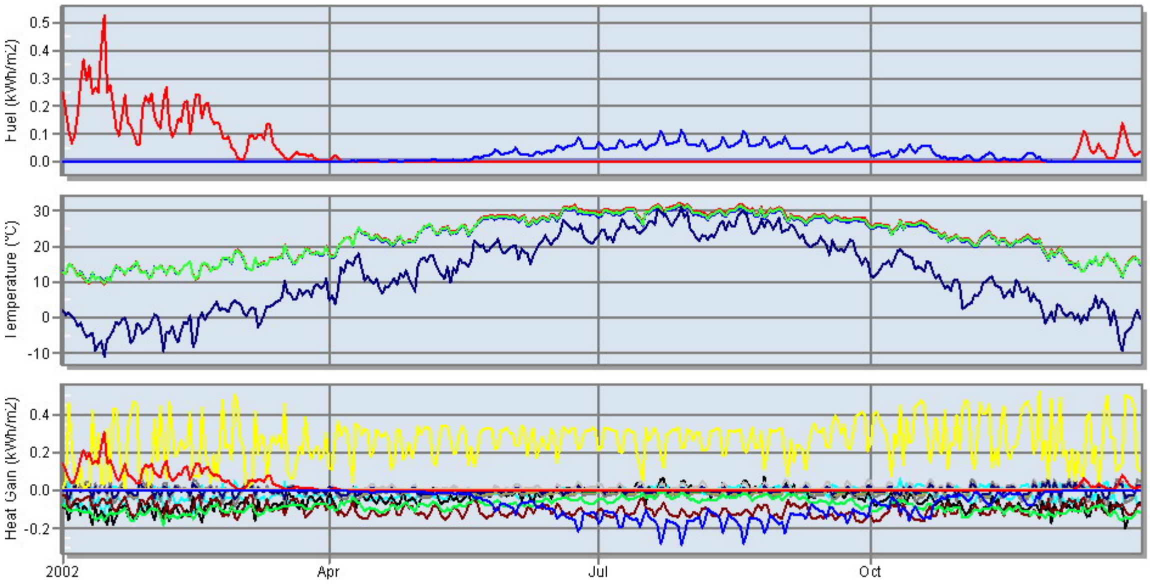


1 (Existing Building)

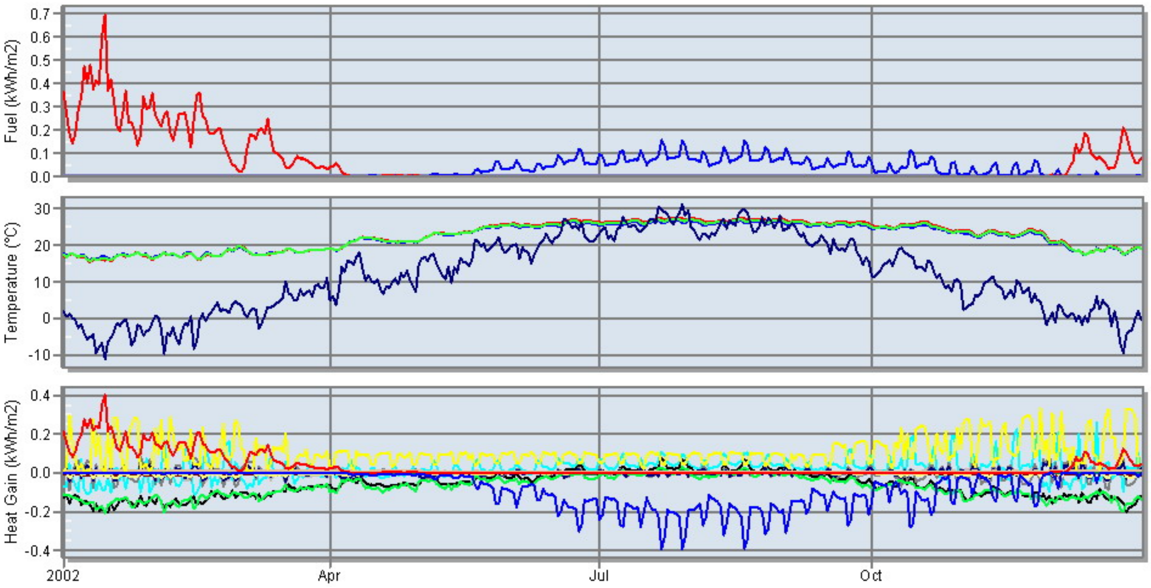
1+ Insulated wall & window



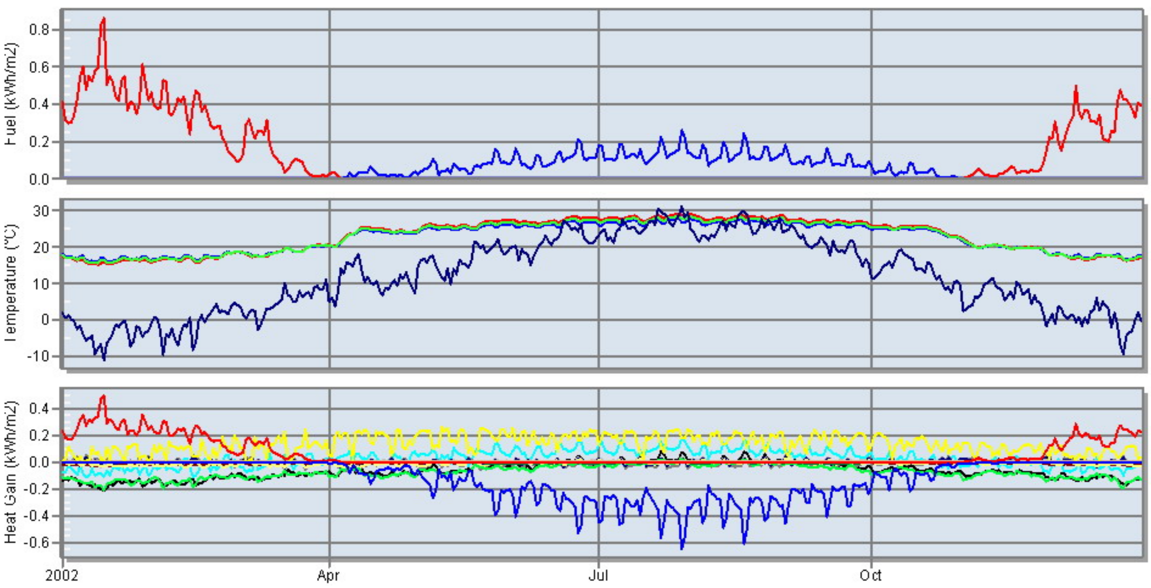
2 (1 Story)



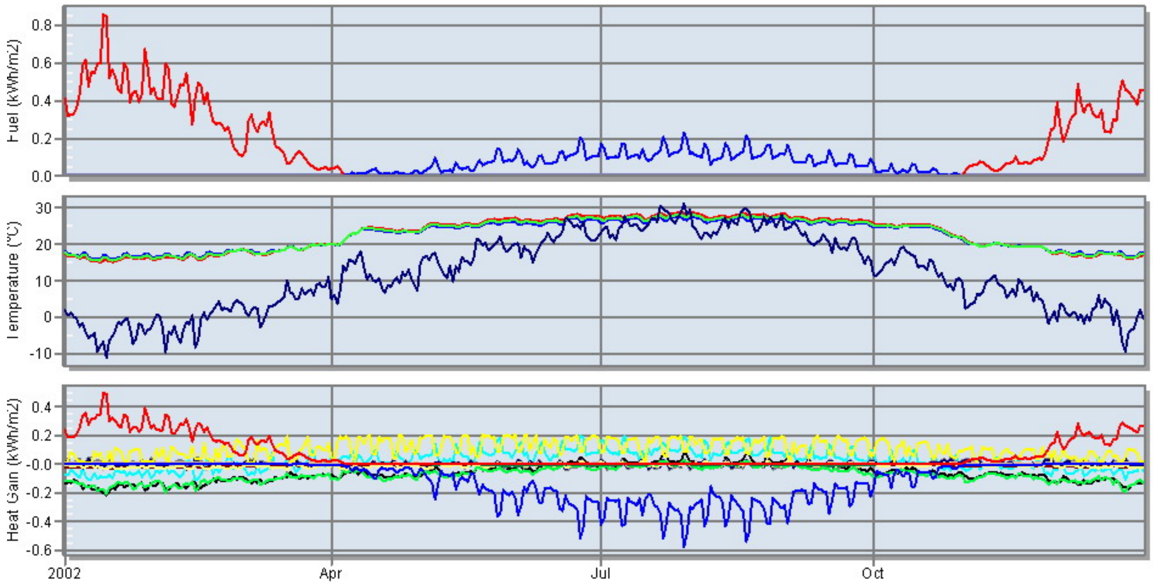
2 (6 Story)



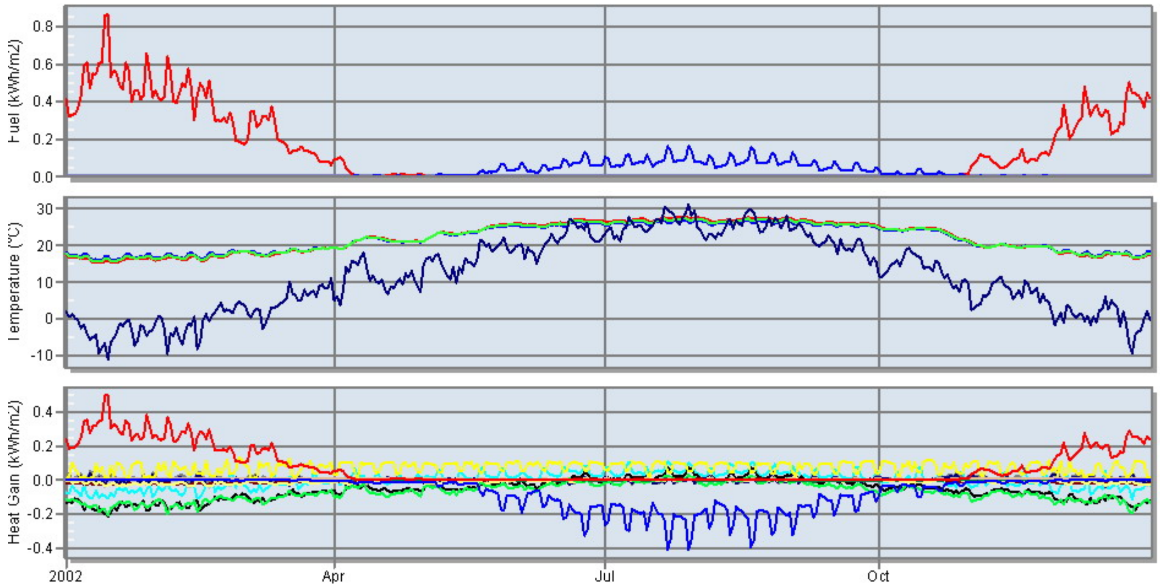
2 (East-facing)



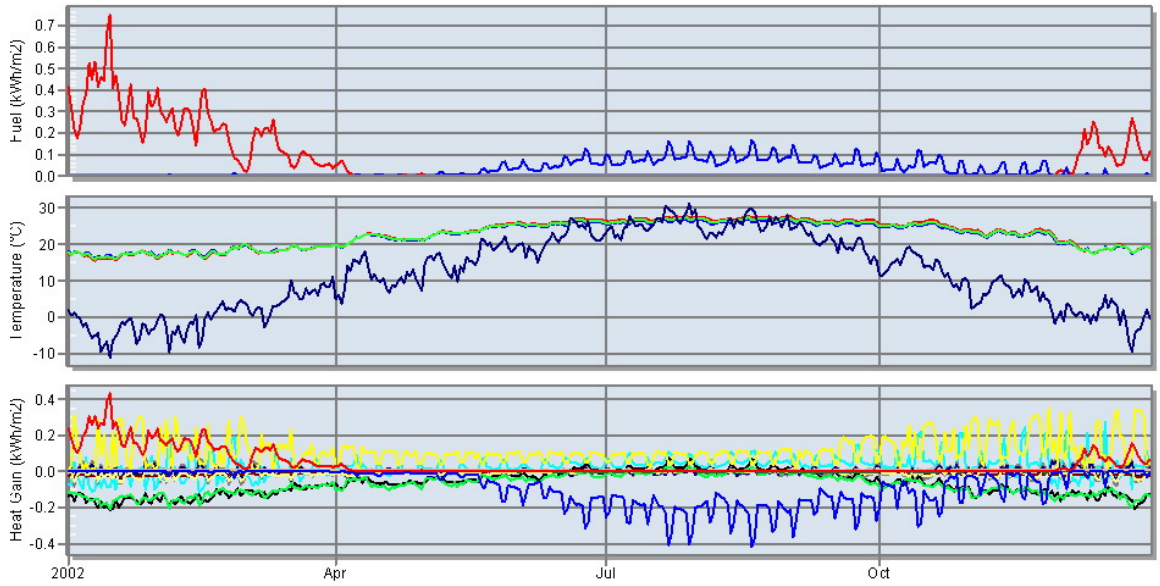
2 (West-facing)



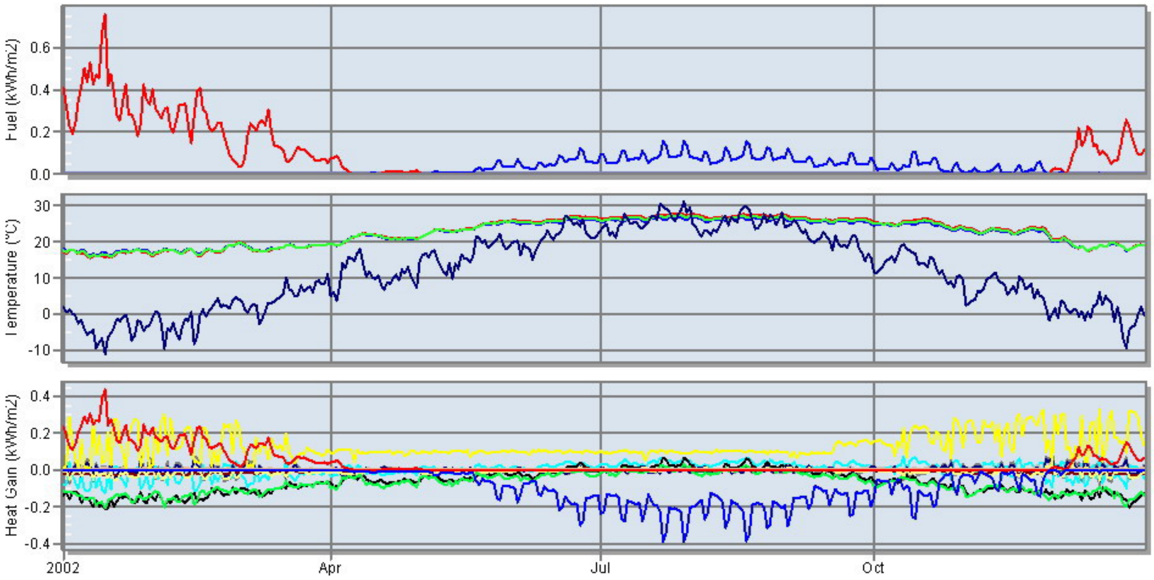
2 (North-facing)



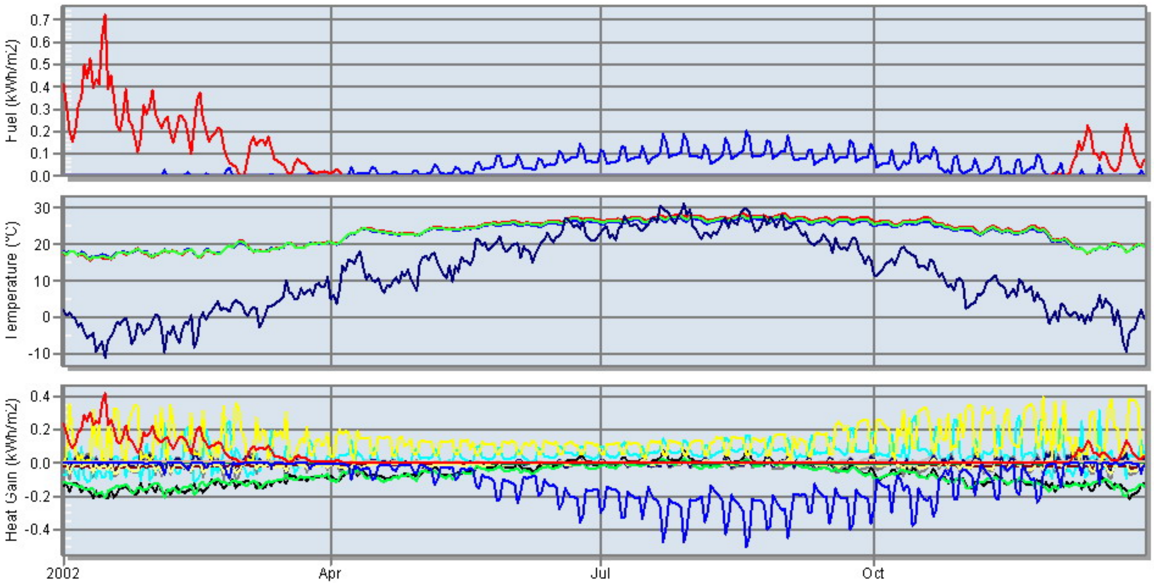
2 + 0.5m Overhang



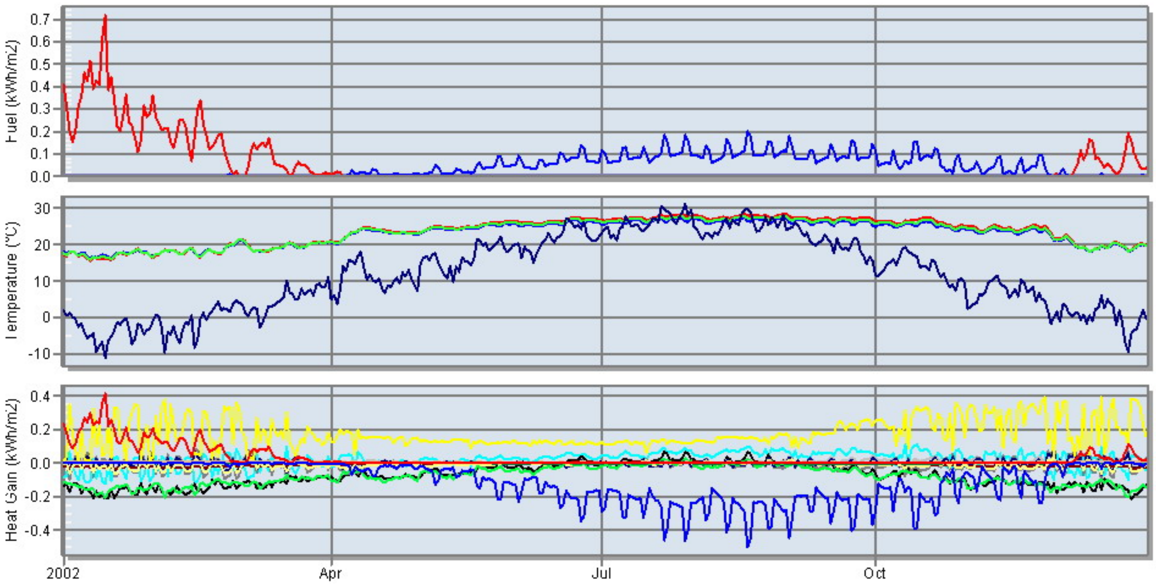
2 + No Blinds



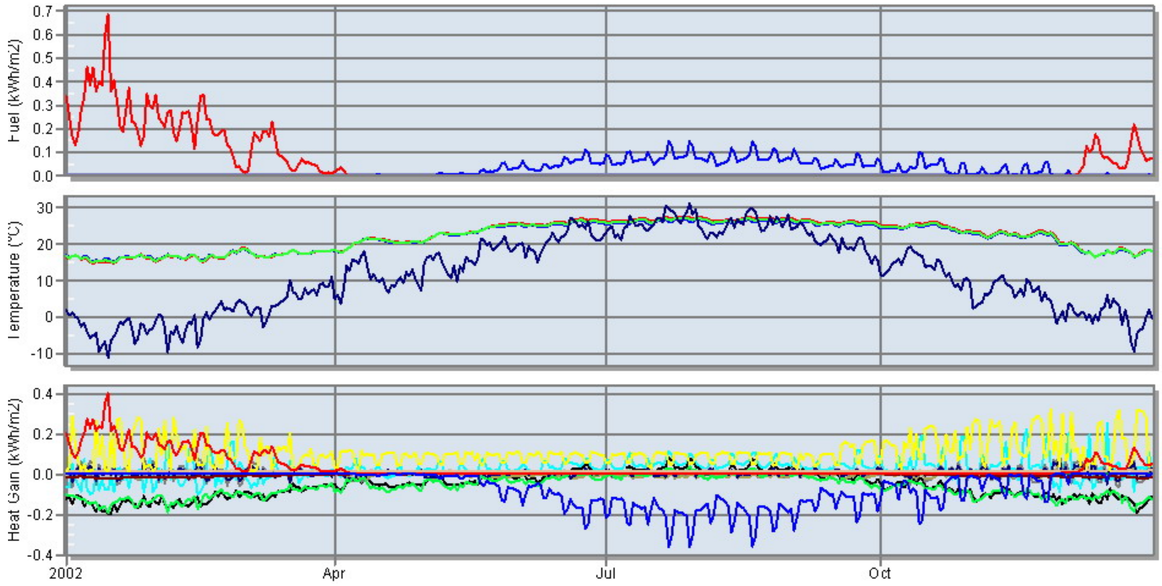
2 + No Overhang



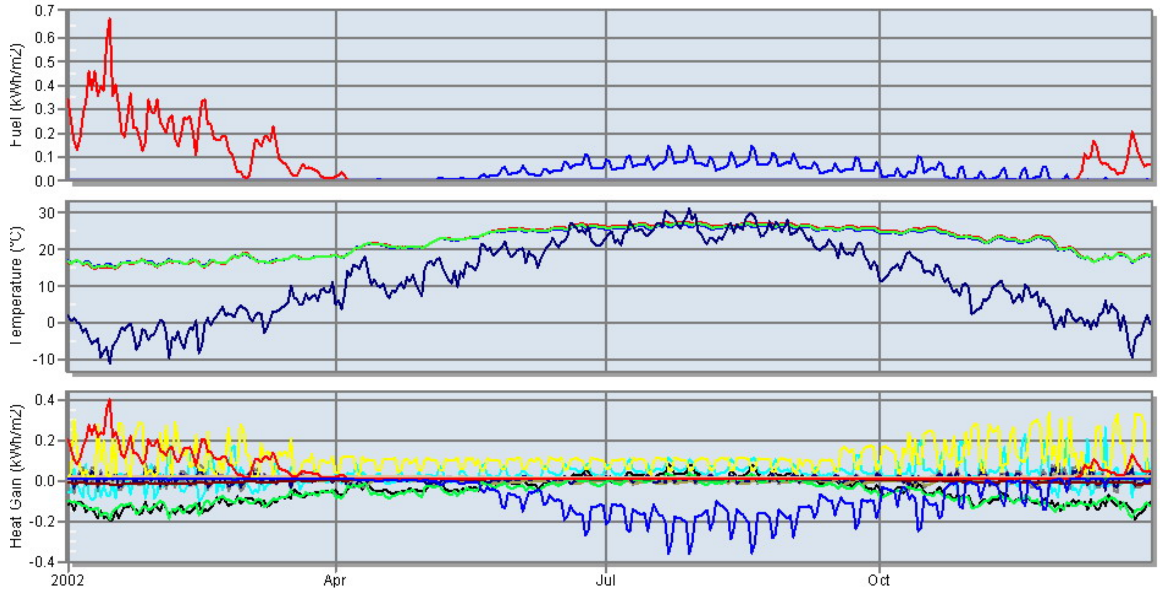
2 + No Overhang & Blinds



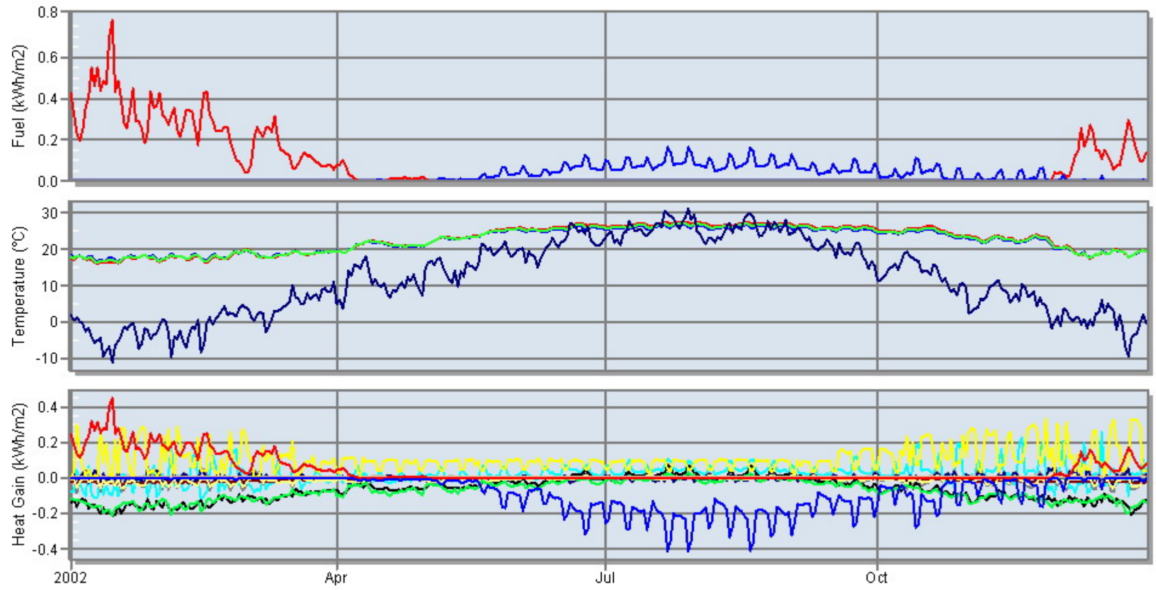
2 + on earth



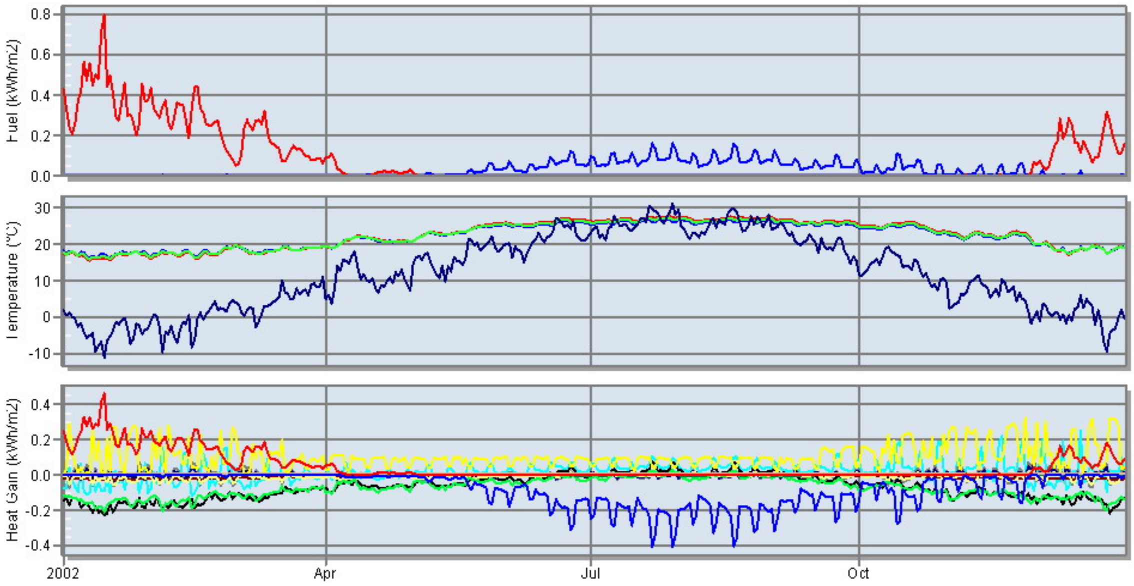
2+ on earth (short wall)



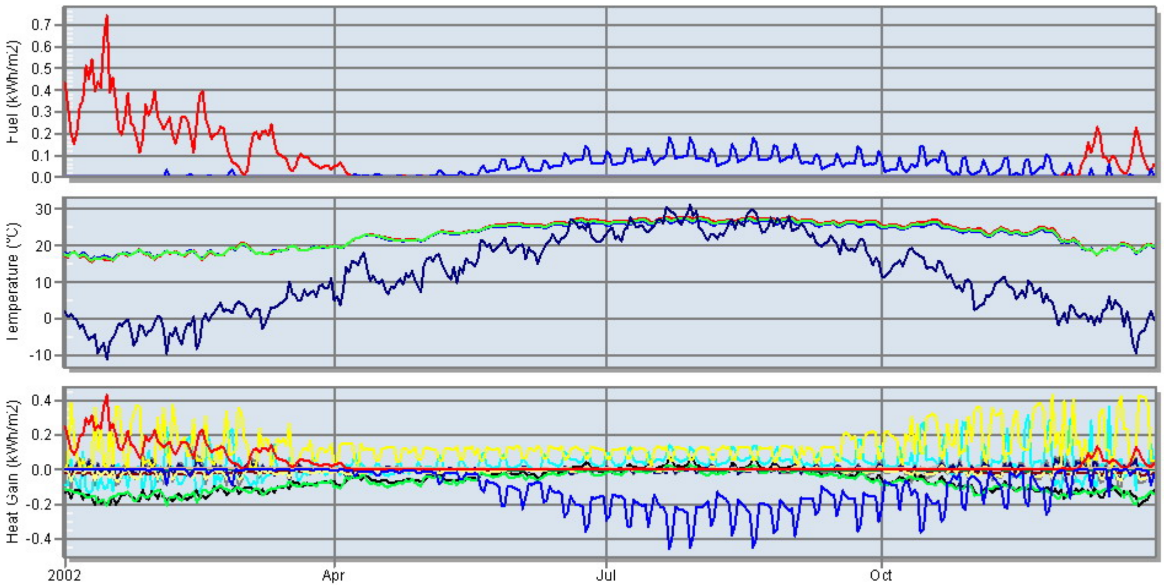
2 + No Staircase



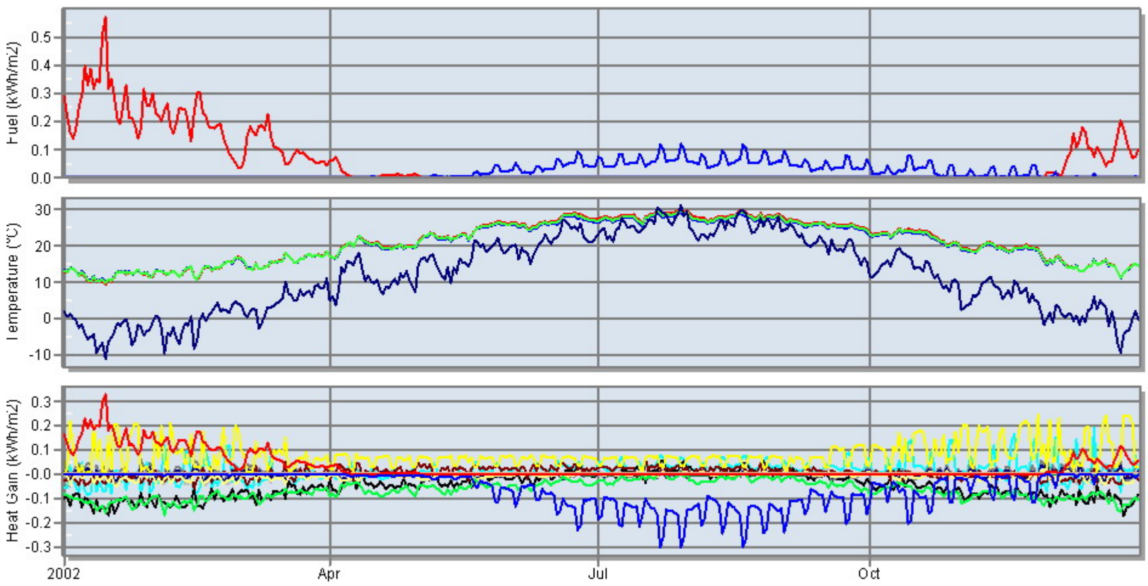
2 + Non door buffer zone



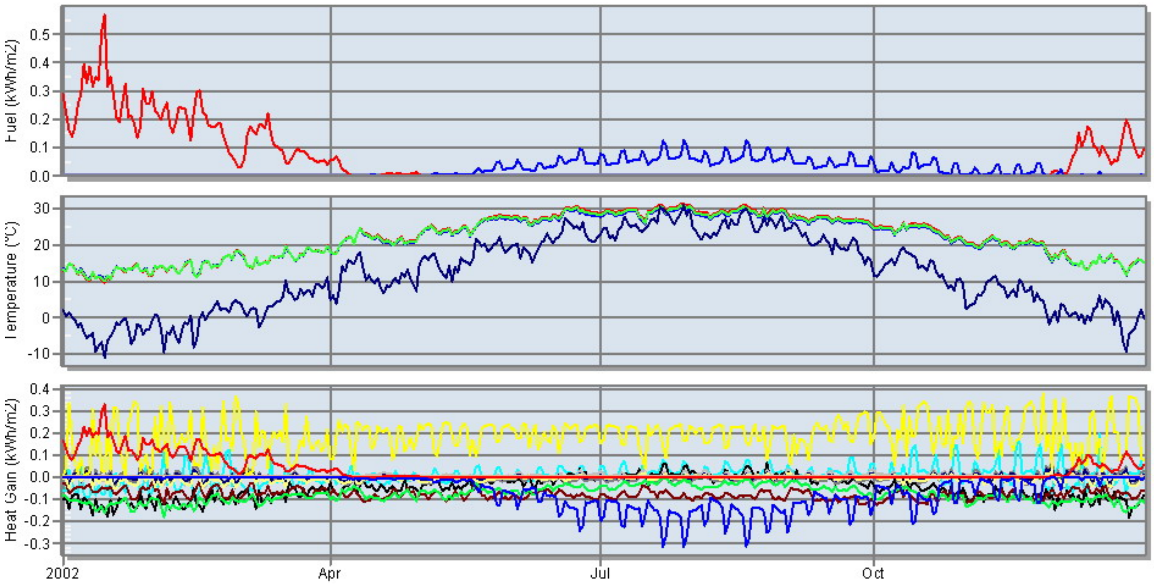
2 + Large South window



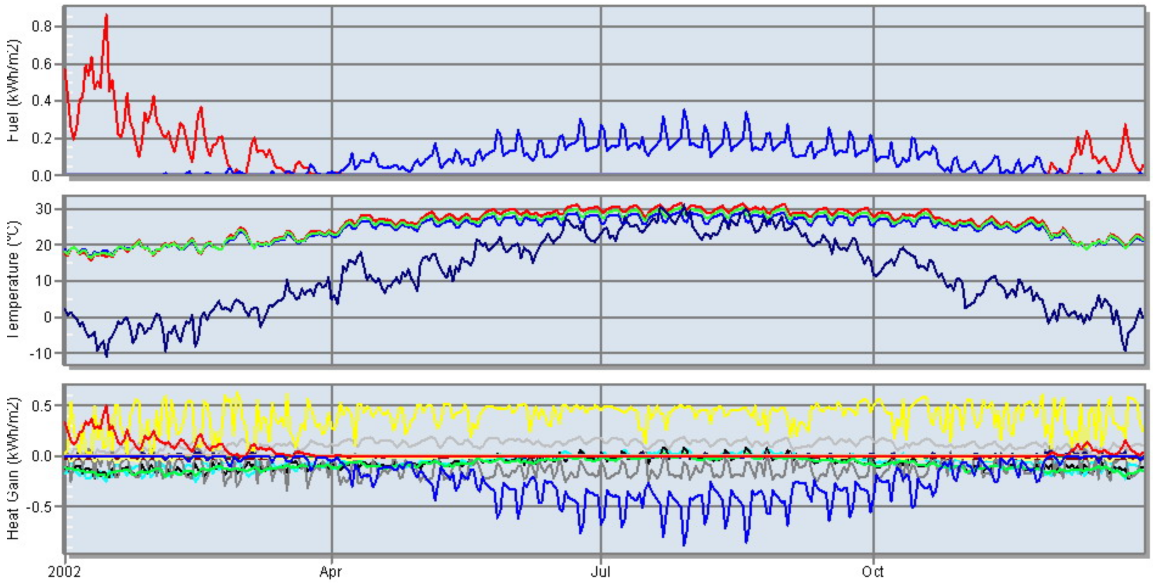
2 + Pitched roof (3)



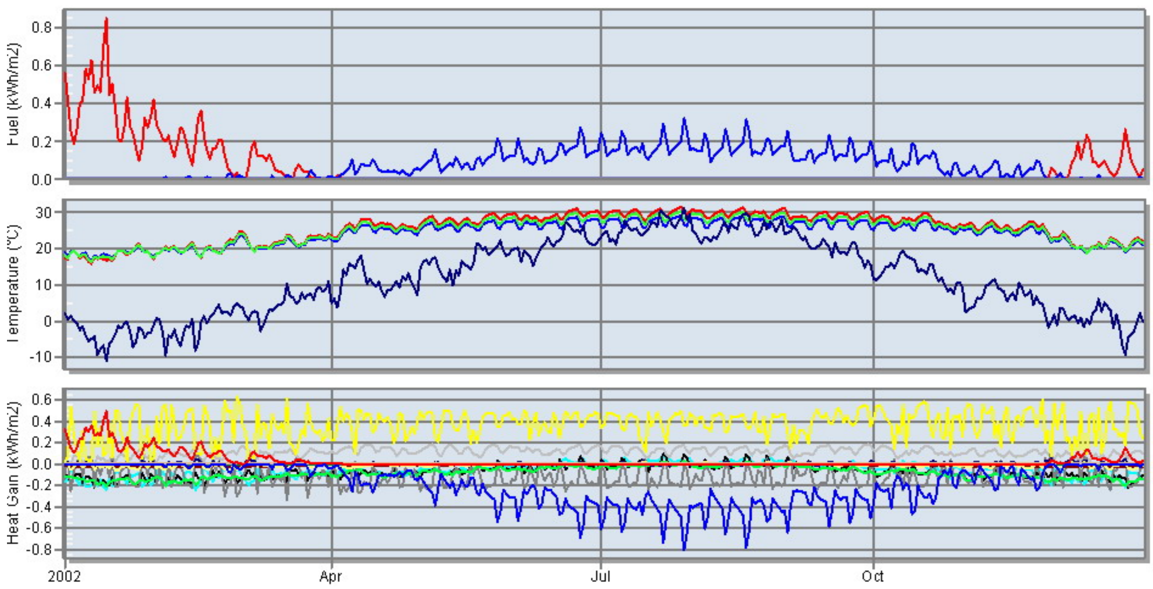
3 + Skylight (4)



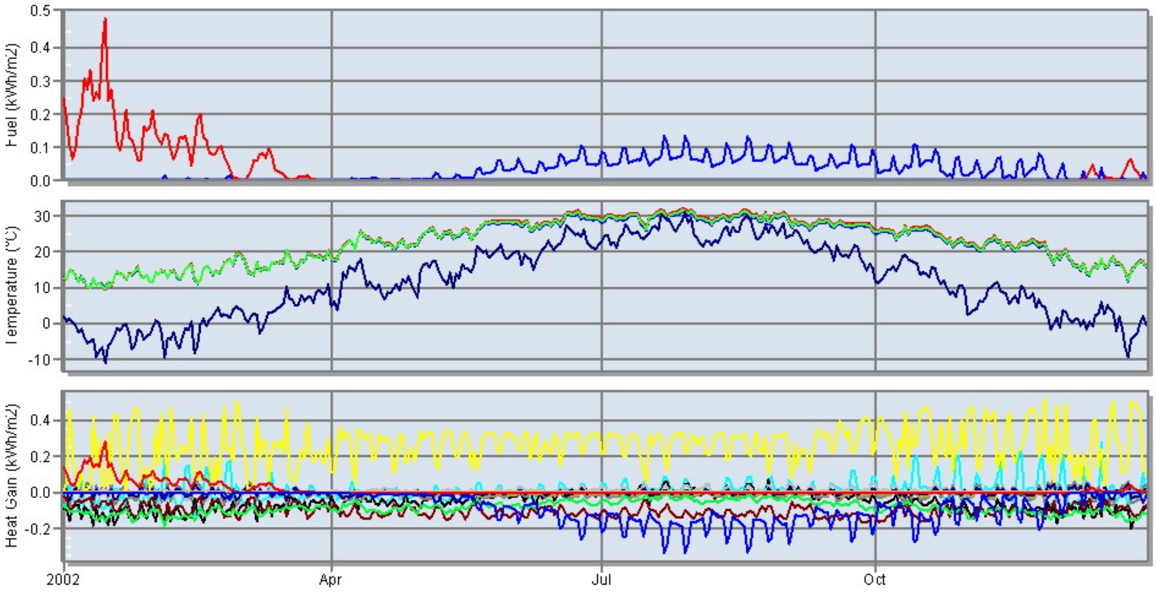
4 + Attic + Large skylight (5)



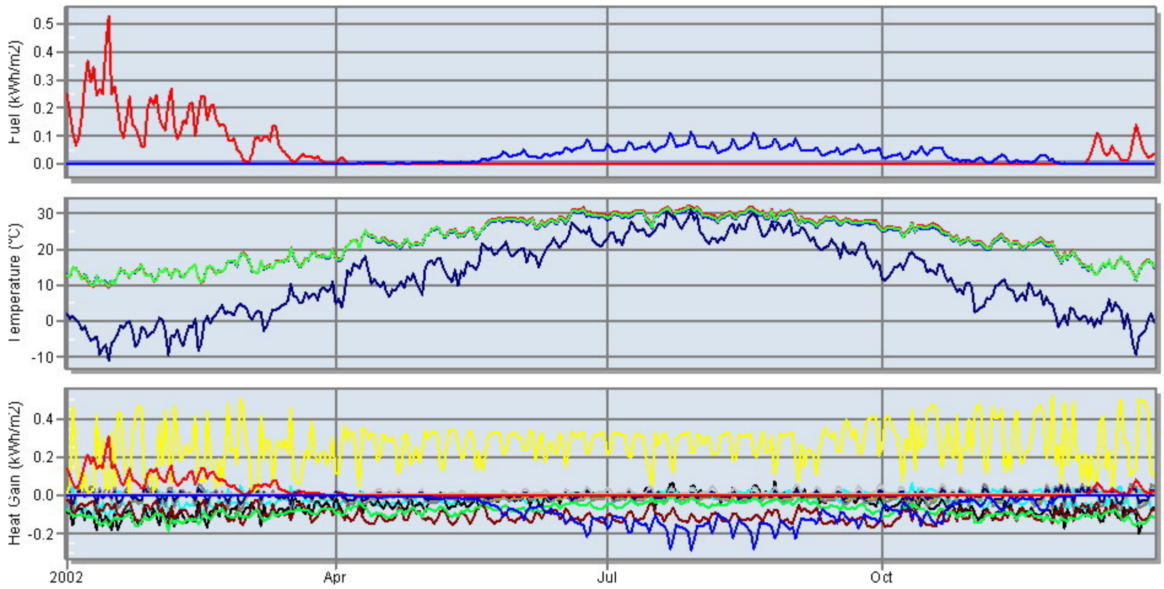
5 + Controlled blinds



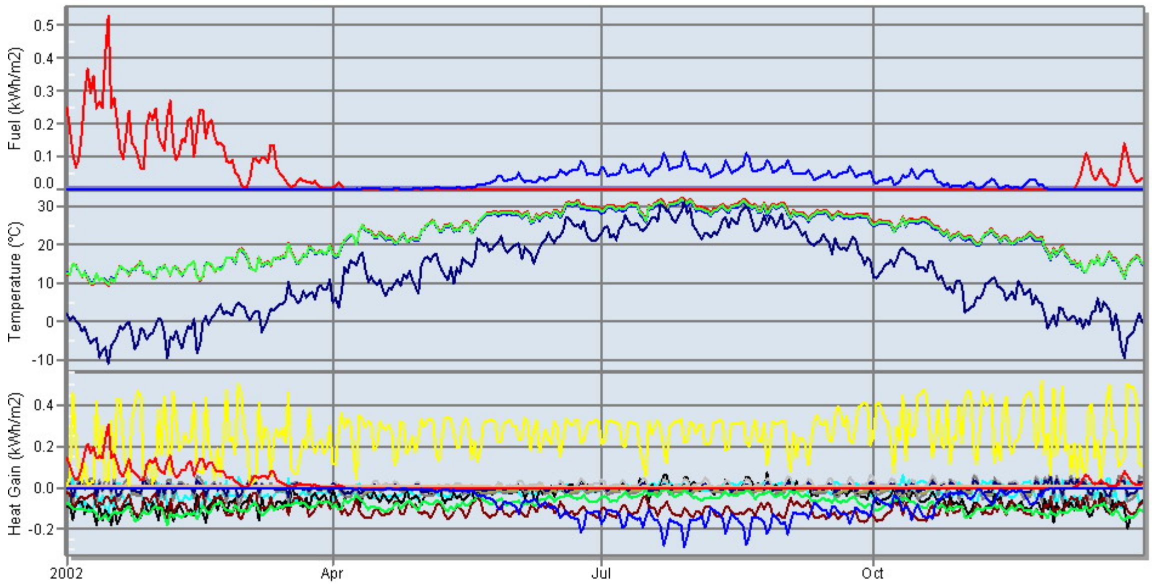
6 (Optimum)



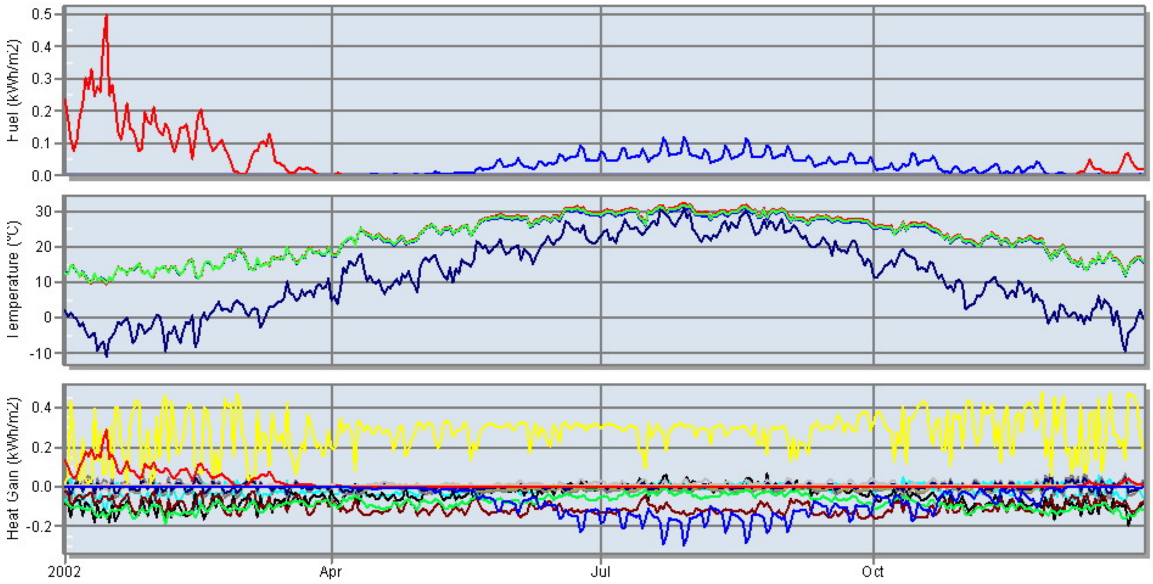
6 + exterior blinds (7)



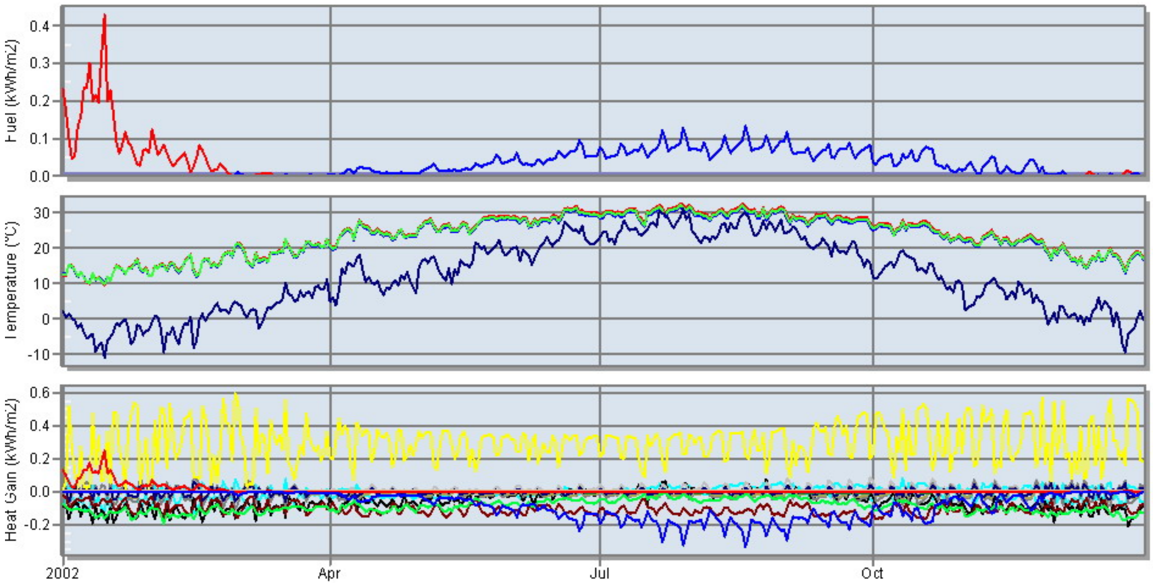
7 + Controlled Blinds (8)



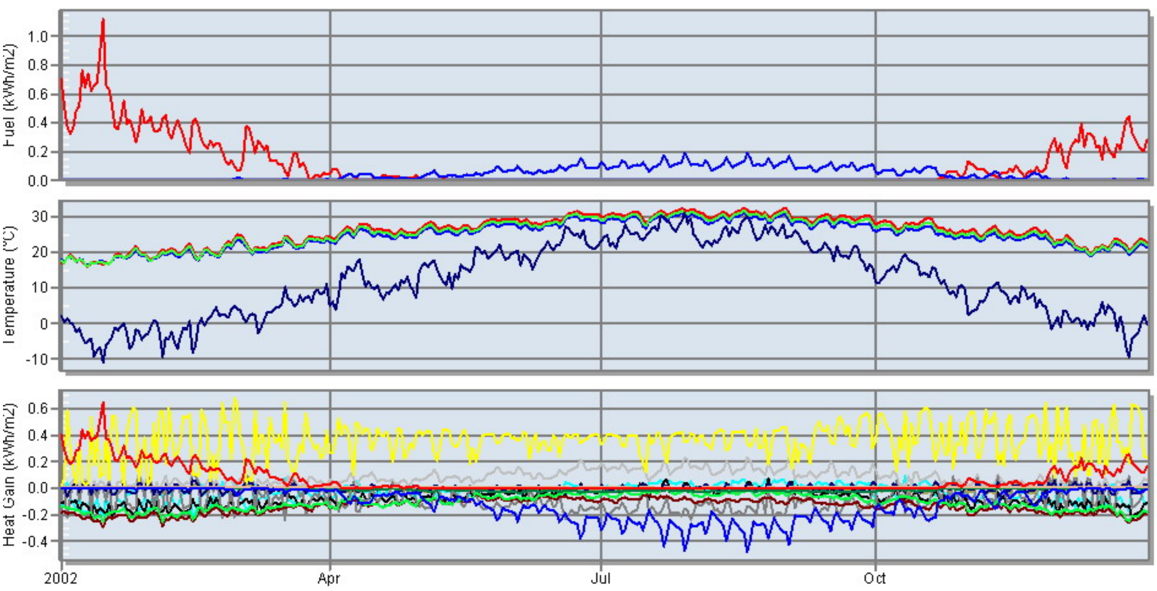
8 + Fin



8 + No Overhang (9)



9 + N+E+W window (4 story)



EnergyPlus output data of simulation of one of simulated buildings

Program Version: **EnergyPlus 2.0.0.025, 07.05.2003 16:58**
Tabular Output Report in Format: **HTML**
Building: **Building**
Environment: **TABRIZ - IRN 'METEONORM' WMO#=407060**
Simulation Timestamp: **2003-05-07 16:59:47**

Report: **Annual Building Utility Performance Summary**
For: **Entire Facility**
Timestamp: **2003-05-07 16:59:47**
Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy (kWh)	Energy Per Total Building Area (kWh/m2)	Energy Per Conditioned Building Area (kWh/m2)
Total Site Energy	8857.09	32.20	37.31
Net Site Energy	8857.09	32.20	37.31
Total Source Energy	23114.77	84.03	97.37
Net Source Energy	23114.77	84.03	97.37

Building Area

	Area (m2)
Total Building Area	275.07
Net Conditioned Building Area	237.38

End Uses

	Electricity (kWh)	Natural Gas (kWh)	Other Fuel (kWh)	Purchased Cooling (kWh)	Purchased Heating (kWh)	Water (m3)
Heating	0.00	2369.48	0.00	0.00	0.00	0.00
Cooling	2010.64	0.00	0.00	0.00	0.00	0.00
Interior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	2700.39	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	1776.58	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	6487.61	2369.48	0.00	0.00	0.00	0.00

End Uses By Subcategory

	Subcategory	Electricity (kWh)	Natural Gas (kWh)	Other Fuel (kWh)	Purchased Cooling (kWh)	Purchased Heating (kWh)	Water (m3)
Heating	General	0.00	2369.48	0.00	0.00	0.00	0.00
Cooling	General	2010.64	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#15565#05	491.22	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15595#05		191.33	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15616#05		211.12	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15754#05		491.22	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15784#05		191.33	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15805#05		211.12	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15681#05		491.22	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15697#05		19.38	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15711#05		191.33	0.00	0.00	0.00	0.00	0.00
ELECTRIC EQUIPMENT#15732#05		211.12	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	1776.58	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity (kWh/m2)	Natural Gas Intensity (kWh/m2)	Other Fuel Intensity (kWh/m2)	Purchased Cooling Intensity (kWh/m2)	Purchased Heating Intensity (kWh/m2)	Water Intensity (m3/m2)
Lighting	0.00	0.00	0.00	0.00	0.00	0.00
HVAC	15.95	9.98	0.00	0.00	0.00	0.00
Other	11.38	0.00	0.00	0.00	0.00	0.00
Total	27.33	9.98	0.00	0.00	0.00	0.00

Utility Use Per Total Floor Area

	Electricity Intensity (kWh/m2)	Natural Gas Intensity (kWh/m2)	Other Fuel Intensity (kWh/m2)	Purchased Cooling Intensity (kWh/m2)	Purchased Heating Intensity (kWh/m2)	Water Intensity (m3/m2)
Lighting	0.00	0.00	0.00	0.00	0.00	0.00
HVAC	13.77	8.61	0.00	0.00	0.00	0.00
Other	9.82	0.00	0.00	0.00	0.00	0.00
Total	23.59	8.61	0.00	0.00	0.00	0.00

Electric Loads Satisfied

	Electricity (kWh)	Percent Electricity (%)
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power*	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	6487.61	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	6487.61	100.00
Total On-Site and Utility Electric Sources	6487.61	100.00
Total Electricity End Uses	6487.61	100.00

On-Site Thermal Sources

	Heat (kWh)	Percent Heat (%)
Water-Side Heat Recovery	0.00	0.00
Air to Air Heat Recovery for Cooling	257.87	12.98
Air to Air Heat Recovery for Heating	1728.67	87.02
High-Temperature Geothermal*	0.00	0.00
Solar Water Thermal	0.00	0.00
Solar Air Thermal	0.00	0.00
Total On-Site Thermal Sources	1986.54	100.00

Report: **Input Verification and Results Summary**
For: **Entire Facility**
Timestamp: **2003-05-07 16:59:47**

GENERAL

	Value
Program Version and Build	EnergyPlus 2.0.0.025, 07.05.2003 16:58
Weather	TABRIZ - IRN 'METEONORM' WMO#=407060
Latitude (deg)	38.13
Longitude (deg)	46.28
Elevation (m)	1364.00
Time Zone	4.00
North Axis Angle (deg)	350.00
Hours Simulated (hrs)	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area (m2)	394.56	114.72	82.56	114.72	82.56
Window Area (m2)	95.65	10.02	0.00	85.63	0.00
Window-Wall Ratio (%)	2.76	8.74	0.00	74.64	0.00

Skylight-Roof Ratio

	Total
Gross Roof Area (m2)	91.69
Skylight Area (m2)	0.00
Skylight-Roof Ratio (%)	0.00

PERFORMANCE

Zone Summary

	Area (m2)	Conditioned (Y/N)	Volume (m3)	Multipliers	Gross Wall Area (m2)	Window Area (m2)	Lighting (W/m2)	People (m2/person)	Plug and Process (W/m2)
15557	10.21	Yes	32.67	1.00	10.05	1.10	0.0000	50.00	0.0000
15565	34.29	Yes	109.72	1.00	36.06	14.90	0.0000	50.00	5.0000
15581	3.27	Yes	10.46	1.00	0.00	0.00	0.0000	50.00	0.0000
15588	3.27	Yes	10.46	1.00	7.46	0.00	0.0000	50.00	0.0000
15595	13.36	Yes	42.74	1.00	26.29	10.62	0.0000	50.00	5.0000
15607	9.98	No	31.95	1.00	21.16	1.10	0.0000	50.00	0.0000
15616	14.74	Yes	47.16	1.00	24.91	1.10	0.0000	50.00	5.0000
15623	2.58	No	8.25	1.00	5.60	2.65	0.0000	50.00	0.0000
15746	10.21	Yes	32.67	1.00	10.05	1.10	0.0000	0.31	0.0000
15754	34.29	Yes	109.72	1.00	36.06	14.92	0.0000	50.00	5.0000
15770	3.27	Yes	10.46	1.00	0.00	0.00	0.0000	50.00	0.0000
15777	3.27	Yes	10.46	1.00	7.46	0.00	0.0000	50.00	0.0000
15784	13.36	Yes	42.74	1.00	26.29	10.60	0.0000	50.00	5.0000
15796	9.98	No	31.95	1.00	21.16	1.10	0.0000	50.00	0.0000
15805	14.74	Yes	47.16	1.00	24.91	1.10	0.0000	50.00	5.0000
15812	2.58	No	8.25	1.00	5.60	2.64	0.0000	50.00	0.0000
15673	10.21	Yes	32.67	1.00	10.05	1.10	0.0000	50.00	0.0000
15681	34.29	Yes	109.72	1.00	36.06	14.95	0.0000	50.00	5.0000
15697	3.27	Yes	10.46	1.00	0.00	0.00	0.0000	50.00	1.9999
15704	3.27	Yes	10.46	1.00	7.46	0.00	0.0000	50.00	0.0000
15711	13.36	Yes	42.74	1.00	26.29	10.62	0.0000	50.00	5.0000
15723	9.98	No	31.95	1.00	21.16	1.10	0.0000	50.00	0.0000
15732	14.74	Yes	47.16	1.00	24.91	1.10	0.0000	50.00	5.0000
15739	2.58	No	8.25	1.00	5.60	2.65	0.0000	50.00	0.0000

Report: **Climate Summary**
For: **Entire Facility**
Timestamp: **2003-05-07 16:59:47**

Design Day

	Maximum Dry Bulb (C)	Daily Tempera-ture Range (C)	Humidity Value	Humidity Type	Wind Speed (m/s)	Wind Di-rection
SUMMER DESIGN DAY IN BUILDING 7	35.10	12.00	16.20	Wet-Bulb	0.00	0.00
WINTER DESIGN DAY IN BUILDING 7	-10.70	0.00	-10.70	Wet-Bulb	10.50	0.00

Report: **Equipment Summary**
For: **Entire Facility**
Timestamp: **2003-05-07 16:59:47**

DX Coils

	Type	Nominal Capacity (W)	Nominal ficiency (W/W)
15557 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	372.78	3.00
15565 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	2109.77	3.00
15581 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	570.17	3.00
15595 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	1521.82	3.00
15616 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	484.39	3.00
15746 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	2899.84	3.00
15754 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	2949.94	3.00
15770 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	757.50	3.00
15784 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	2293.57	3.00
15805 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	654.26	3.00
15673 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	646.19	3.00
15681 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	3585.71	3.00
15697 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	913.70	3.00
15704 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	366.01	3.00
15711 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	2699.16	3.00
15732 AHU COOLING COIL	COIL:DX:COOLINGBYPASSFACTOREMPIRICAL	786.88	3.00

Fans

	Type	Total Efficiency (W/W)	Delta Pressure (pa)	Max Flow Rate (m3/s)	Motor Heat In Air Fraction	End Use
15557 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.02	1.00	General
15565 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.13	1.00	General
15581 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.03	1.00	General
15588 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.02	1.00	General
15595 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.09	1.00	General
15616 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.03	1.00	General
15746 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.14	1.00	General
15754 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.18	1.00	General
15770 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.05	1.00	General
15777 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.02	1.00	General
15784 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.14	1.00	General
15805 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.04	1.00	General
15673 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.04	1.00	General
15681 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.22	1.00	General
15697 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.06	1.00	General
15704 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.02	1.00	General
15711 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.16	1.00	General
15732 AHU SUPPLY FAN	SIMPLE	0.70	100.00	0.05	1.00	General

Report: **Envelope Summary**
For: **Entire Facility**
Timestamp: **2003-05-07 16:59:47**

Opaque Exterior

	Construction	Reflectance	U-Factor	Gross Area (m2)	Azimuth (deg)	Tilt (deg)	Cardinal Direction
W_15557_4_0	7	0.30	0.26	10.05	350.00	90.00	N
S_15557_0_0	1	0.30	0.15	10.21	350.00	180.00	
W_15565_7_0	7	0.30	0.26	14.55	260.00	90.00	W
W_15565_8_0	7	0.30	0.26	18.72	170.00	90.00	S
W_15565_9_0	7	0.30	0.26	2.56	80.00	90.00	E
W_15565_10_0	7	0.30	0.26	0.22	170.00	90.00	S
S_15565_0_0	1	0.30	0.15	34.29	350.00	180.00	
S_15581_0_0	1	0.30	0.15	3.27	350.00	180.00	
W_15588_2_0	7	0.30	0.26	7.46	80.00	90.00	E
S_15588_0_0	1	0.30	0.15	3.27	350.00	180.00	
W_15595_2_0	7	0.30	0.26	10.03	80.00	90.00	E
W_15595_8_0	7	0.30	0.26	0.26	170.00	90.00	S
W_15595_9_0	7	0.30	0.26	2.56	260.00	90.00	W
W_15595_10_0	7	0.30	0.26	13.44	170.00	90.00	S
S_15595_0_0	1	0.30	0.15	13.36	350.00	180.00	
W_15607_2_0	7	0.30	0.26	7.46	80.00	90.00	E
W_15607_3_0	7	0.30	0.26	13.70	350.00	90.00	N
S_15607_0_0	1	0.30	0.15	9.98	350.00	180.00	
W_15616_3_0	7	0.30	0.26	14.50	350.00	90.00	N
W_15616_4_0	7	0.30	0.26	10.41	260.00	90.00	W
S_15616_0_0	1	0.30	0.15	14.74	350.00	180.00	
W_15623_5_0	7	0.30	0.26	5.60	170.00	90.00	S
S_15623_0_0	1	0.30	0.15	2.58	350.00	180.00	
W_15746_4_0	7	0.30	0.26	10.05	350.00	90.00	N
W_15754_7_0	7	0.30	0.26	14.55	260.00	90.00	W
W_15754_8_0	7	0.30	0.26	18.72	170.00	90.00	S
W_15754_9_0	7	0.30	0.26	2.56	80.00	90.00	E
W_15754_10_0	7	0.30	0.26	0.22	170.00	90.00	S
W_15777_2_0	7	0.30	0.26	7.46	80.00	90.00	E
W_15784_2_0	7	0.30	0.26	10.03	80.00	90.00	E
W_15784_8_0	7	0.30	0.26	0.26	170.00	90.00	S
W_15784_9_0	7	0.30	0.26	2.56	260.00	90.00	W
W_15784_10_0	7	0.30	0.26	13.44	170.00	90.00	S
W_15796_2_0	7	0.30	0.26	7.46	80.00	90.00	E
W_15796_3_0	7	0.30	0.26	13.70	350.00	90.00	N
W_15805_3_0	7	0.30	0.26	14.50	350.00	90.00	N
W_15805_4_0	7	0.30	0.26	10.41	260.00	90.00	W
W_15812_5_0	7	0.30	0.26	5.60	170.00	90.00	S
W_15673_4_0	7	0.30	0.26	10.05	350.00	90.00	N
R_15673_1_0	15	0.30	0.15	10.21	170.00	0.00	
W_15681_7_0	7	0.30	0.26	14.55	260.00	90.00	W
W_15681_8_0	7	0.30	0.26	18.72	170.00	90.00	S
W_15681_9_0	7	0.30	0.26	2.56	80.00	90.00	E

W_15681_10_0	7	0.30	0.26	0.22	170.00	90.00	S
R_15681_1_0	15	0.30	0.15	34.29	170.00	0.00	
R_15697_1_0	15	0.30	0.15	3.27	170.00	0.00	
W_15704_2_0	7	0.30	0.26	7.46	80.00	90.00	E
R_15704_1_0	15	0.30	0.15	3.27	170.00	0.00	
W_15711_2_0	7	0.30	0.26	10.03	80.00	90.00	E
W_15711_8_0	7	0.30	0.26	0.26	170.00	90.00	S
W_15711_9_0	7	0.30	0.26	2.56	260.00	90.00	W
W_15711_10_0	7	0.30	0.26	13.44	170.00	90.00	S
R_15711_1_0	15	0.30	0.15	13.36	170.00	0.00	
W_15723_2_0	7	0.30	0.26	7.46	80.00	90.00	E
W_15723_3_0	7	0.30	0.26	13.70	350.00	90.00	N
R_15723_1_0	15	0.30	0.15	9.98	170.00	0.00	
W_15732_3_0	7	0.30	0.26	14.50	350.00	90.00	N
W_15732_4_0	7	0.30	0.26	10.41	260.00	90.00	W
R_15732_1_0	15	0.30	0.15	14.74	170.00	0.00	
W_15739_5_0	7	0.30	0.26	5.60	170.00	90.00	S
R_15739_1_0	15	0.30	0.15	2.58	170.00	0.00	

Fenestration

	Construction	Area (m2)	U-Factor	SHGC	Parent Surface
W_15557_4_0_0_0	1001	1.11	0.78	0.470	W_15557_4_0
W_15565_8_0_0_0	1001	15.05	0.78	0.470	W_15565_8_0
W_15595_10_0_0_0	1001	10.78	0.78	0.470	W_15595_10_0
W_15607_3_0_0_1	1001	1.11	0.78	0.470	W_15607_3_0
W_15616_3_0_0_0	1001	1.11	0.78	0.470	W_15616_3_0
W_15623_5_0_0_0	1001	2.70	0.78	0.470	W_15623_5_0
W_15746_4_0_0_0	1001	1.11	0.78	0.470	W_15746_4_0
W_15754_8_0_0_0	1001	15.07	0.78	0.470	W_15754_8_0
W_15784_10_0_0_0	1001	10.75	0.78	0.470	W_15784_10_0
W_15796_3_0_0_0	1001	1.11	0.78	0.470	W_15796_3_0
W_15805_3_0_0_0	1001	1.11	0.78	0.470	W_15805_3_0
W_15812_5_0_0_0	1001	2.69	0.78	0.470	W_15812_5_0
W_15673_4_0_0_0	1001	1.11	0.78	0.470	W_15673_4_0
W_15681_8_0_0_0	1001	15.11	0.78	0.470	W_15681_8_0
W_15711_10_0_0_0	1001	10.77	0.78	0.470	W_15711_10_0
W_15723_3_0_0_0	1001	1.11	0.78	0.470	W_15723_3_0
W_15732_3_0_0_0	1001	1.11	0.78	0.470	W_15732_3_0
W_15739_5_0_0_0	1001	2.69	0.78	0.470	W_15739_5_0