young cities
Developing Urban Energy Efficiency
Tehrān-Karaj

08

Young Cities Research Paper Series, Volume 08

Green Office Buildings

Low Energy Demand through Architectural Energy Efficiency

Farshad Nasrollahi

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BHRC

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Edited by Technische Universität Berlin and
Road, Housing & Urban Development Research Center, Tehran

German-Iranian Research Project
Young Cities
Developing Energy-Efficient Urban Fabric in the Tehran-Karaj Region

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P.O. Box 13145-1696
Sheikh Fazlollah Noori Highway
Tehran | Islamic Republic of Iran
www.bhrc.ac.ir

Design/Typesetting büro-d | Communication Design Berlin

Publisher
Universitätsverlag der TU Berlin
Universitätsbibliothek
Fasanenstr. 88
10623 Berlin | Germany
www.univerlag.tu-berlin.de

BHRC
P.O. Box 13145-1696
Sheikh Fazlollah Noori Highway
Tehran | Islamic Republic of Iran
www.bhrc.ac.ir

ISSN 2193-6099 (Print)
ISSN 2193-6102 (Online)
ISBN 978-3-7983-2578-4 (Print)
ISBN 978-3-7983-2579-1 (Online)

ISBN 978-600-5392-82-1

Simultaneously published online on the Digital Repository of the Technische Universität Berlin
URL http://opus.kobv.de/tuberlin/volltexte/2013/4047/
URN urn:nbn:de:kobv:83-opus-40476
[http://nbn-resolving.de/urn:nbn:de:kobv:83-opus-40476]

Young Cities Research Paper Series
Editors: Rudolf Schäfer, Farshad Nasrollahi, Holger Ohlenburg, Cornelia Saalmann, Florian Stellmacher

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All texts are based on scientific research performed within the Young Cities Project. All pictures, tables and graphics are courtesy of the respective article's authors, unless otherwise mentioned.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.dnb.de

Acknowledgements

The eighth volume of the “Young Cities Research Paper Series” with the title “Green Office Buildings—Low Energy Demand through Architectural Energy Efficiency” presents the results gained within the Young Cities Research Project, which was sponsored by the German Federal Ministry of Education and Research (BMBF). I would therefore like to express my sincere thanks to the Federal Ministry of Education and Research for its financial support. My thanks are also due to my university, bearing the primary responsibility of the project, and the heads of partner institutions, among others the Berlin Institute of Technology (Technische Universität Berlin), as well as Prof. Dr. Rudolf Schäfer, director of the Young Cities project, for contributing towards the successful accomplishment of the project.

The studies and research regarding energy efficiency in office buildings published in this volume was performed at the Chair of Building Technology and Architectural Design (Fachgebiet Gebäudetechnik und Entwerfen). I therefore owe special thanks to Prof. Dipl.-Ing. Claus Steffan, the Chairman of this section, for his scientific support in the field of energy efficiency as well as his helpful advice on the design of the New Generation Office Building.

Special thanks go to my student assistant in 2012, Alexander Wanitschke, for participating in the studies on energy-efficient heating and cooling systems and drawing the concepts of the HVAC systems. I am also very grateful to another one of my student assistants, Jakob Kress, for his assistance in preparing design drawings and rendering the perspectives of the New Generation Office Building. I would furthermore like to thank Zofia Bogucka, also a student assistant, for her help in drawing some of the building concepts.

I am also very grateful to Cornelia Saalmann, my colleague on the Board of Editors of the Young Cities Research Paper Series, for her kind cooperation and reliable work in publishing this volume.

Finally, I would like to thank Sharon Heidenreich for her outstanding proofreading of this volume and büro-d for the layout and graphic design.

Farshad Nasrollahi
TU Berlin

The German side of the Young Cities project is partly funded by German Federal Ministry of Education and Research (BMBF).

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Abstract

Due to the depletion of fossil fuels and their environmental damages, reduction of global energy consumption is crucial. As the buildings are responsible for about 40% of global energy consumption, introduction and implementation of energy-efficient buildings can reduces the total energy demand.

The first step towards creating an environmental design and identifying the possibilities for climate responsive architecture should always be an analysis of the climatic data. A variety of tools are nowadays available to understand the climate conditions and create an energy-efficient design. These include graphical means such as the building bio-climatic chart, the psychrometric chart, wind wheels, sun charts and sun shading charts, are required.

The first chapter of this publication shows how the climate data must be analysed and which conclusions can be drawn from these analyses for an environmental design. As the research findings presented in this book are elaborated for Hashtgerd New Town, as the location for the case study project, the climatic conditions of this particular city are used as a basis. The studies have shown that passive solar heat gains and internal heat gains are very important for heating buildings, but that shading devices at windows and natural ventilation are also very important measures for cooling. In Hashtgerd New Town, evaporative cooling suffices to meet almost the total cooling requirements.

Due to the fact that energy savings through cost and energy-intensive measures can only be achieved with a great consumption of resources and CO_2 emissions for their production, it is first of all necessary to apply cost and resource-efficient measures to save energy in buildings. Architectural Energy Efficiency is a parametric method of energy saving which separately studies the effects of various energy-related architectural factors on the energy demands of buildings. Dynamic energy simulation methods are used to find the optimum value for each of the architectural factors, including orientation, building elongation, building form, opening ratio in different orientations, sun shading, natural ventilation etc.

As the architectural design affects the heating and cooling as well as the lighting energy demands of buildings, the criteria for selecting the best variant is best based on the total heating, cooling and lighting energy demand, or the primary energy demand, the CO_2 emissions, energy costs or life cycle costs for all three energy demands.

Architectural Energy Efficiency, as a method for optimizing the architectural design, can be applied to different building types and climates to develop a set of energy saving guidelines for architects and building designers.

In this publication, Architectural Energy Efficiency is implemented in office buildings in the climatic conditions of the Tehran region.

The study has shown that the optimum orientation for a minimum total and primary energy demand is the south orientation. The primary energy demand of north-facing office buildings is also fairly low.

According to the results regarding the window area, the cardinal direction can significantly affect the building's energy demand. For a minimum total energy demand, the optimum window-to-wall ratios for the south, east/west and north-facing facades are 60%, 10 % and 30 % respectively. Buildings with external blinds have their lowest total and primary energy demands at a window-to-wall ratio of 60%. The proportion of window area for each orientation should differ; the optimum window-to-wall ratios for the south, east/west and north-facing facades are 60%, 10% and 30% respectively.

The results regarding shading devices show that large overhangs and an increase of overhang depth raise the total energy demand of office buildings. Office buildings with external blinds require less energy than office buildings without any blinds; however, this is only the case if the blinds are controlled effectively.

The third chapter presents the design process of the New Generation Office Building as an energy and cost-efficient office building. In comparison to an average office building, the energy-efficient design principles, which resulted from the application of Architectural Energy Efficiency in this pilot project, led to energy savings of 50%. Some further energy

saving concepts have been applied in this green office building for additional energy savings. These include an optimal urban and building form, innovative fixed shading devices, a combination of natural ventilation and evaporative cooling, solar reflectors, a mechanical heat recovery system and extensive green roofs.

The last part of the book explores the energy and cost efficiency of heating and cooling systems for energy-efficient office buildings in the climate conditions of Hashtgerd New Town and, in particular, for the New Generation Office Building, as a case study building. The research considers the suitability of solar heating and solar cooling systems in Iran from an economic point of view and determines the optimum area of the solar collector, the size of the buffer tank and the slope of the panels for the New Generation Office Building. The results show that solar energy systems, in place of conventional systems, are not always feasible, since the prices of fossil fuels are still relatively low in Iran, even after reducing the energy subsidies. From an economic point of view, it is therefore more suitable to install a gas heater for heating and an evaporative cooling system for cooling in Iran's current economic conditions. The installation of a subsoil heat exchanger and/or an air-to-air heat exchanger is always worthwhile, as it decreases the heating and cooling energy demands as well as the size of the HVAC system.

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und entwerfen gte
Technische Universität Berlin
Building Technology and Architectural Design
Prof. Claus Steffan

Forewords

This publication presents the research results in the field of energy efficiency in buildings. It illustrates the required steps towards an energy efficient building design, including the analyses of the climate data at the particular location, the building's behavior regarding different architectural factors, the architectural design process as well as the selection of a suitable energy-efficient HVAC system. The research was elaborated in the context of the German-Iranian research project „Young Cities—Developing Energy-Efficient Urban Fabric in the Tehran-Karaj Region".

Architectural Energy Efficiency, as an innovative method of energy saving, is a parametric method which studies the effects of various architectural factors on the energy demand of buildings. The approach uses dynamic energy simulation to identify the optimum value for each architectural factor from an energy efficiency point of view. It is according to these factors that the architectural design affects the heating and cooling as well as the lighting energy demands of buildings. Thus, Architectural Energy Efficiency is a way to minimize the consumption of resources as well as the building costs. The measures of this approach can contribute towards cost-neutral energy savings.

The publication focuses mainly on office buildings; and, among the pilot projects which were conceptualized as the main methodological approach and tool in the Young Cities project, there is an office building designed for the local branch of the Iranian New Town Development Corporation in the emerging new town Hashtgerd.

Prior to every design, the climatic data of the region should be analyzed in order to determine the possibilities for energy savings, in this case it is the climate of Hashtgerd.

The study then presents a systematic concept of Architectural Energy Efficiency, detailing the factors affecting the energy demands of buildings and elaborating the criteria for selecting the best variant in terms of the different energy carriers that provide heating, cooling and lighting, such as the primary energy demand, CO_2 emissions, energy costs, life cycle costs and others.This approach is specified in greater detail in the design of the New Generation Pilot Project Office Building.

The publication also includes the planning process for developing an energy and cost-efficient office building and introduces some further innovative energy saving concepts, which are implemented in the scheme. The author also presents a general concept for the energy-efficient heating and cooling of office buildings and studies the possibilities of using solar heating and cooling in the climatic and economic situations of the research area.

Even though an example climate is applied in the New Generation Office Building to study Architectural Energy Efficiency, the method of energy efficiency as well as the design process can be transferred to other climatic areas, such as in MENA region.

The study also shows that the concept of Architectural Energy Efficiency is a valuable and attractive approach in all situations where the aim is to decrease the energy demand of buildings and the application of cost-intensive measures is not economically viable. This book should become essential reading for all architects and a standard reference for everybody in the construction business.

Prof. Dr. Rudolf Schäfer
TU Berlin

Buildings are responsible for almost 40% of global energy consumption; their saving potentials are therefore considerable. Many factors influence a building's energy demand, such as the architectural design, materials, building services, user behavior etc. Almost all of these factors can be optimized in their design and energy consumption by performing climate simulation modeling.

In this publication, there is a focus on office buildings in the hot and dry climate zone that prevails in the city of Hashtgerd New Town in Iran. The results of the 5-year research program include possibilities to optimize the building concept for very low energy consumption without however increasing the budget.

The research has identified that the architectural design is the most crucial factor for energy saving. The building form, geometry, orientation and window ratio are important measures in this context. The situations both in winter and summer are considered to provide good thermal comfort indoors. Especially the summer case, with the hot climate and the internal heat loads of office building, is a challenging aspect of the design. Solar protection and night cooling are therefore important issues in this process.

Further considerations concern energy-efficient building services for heating and cooling. This book describes ways to generate more energy-efficient office buildings in hot climates, as are also found in the fast growing mega-cities of Latin America and South Asia.

Alongside research and new integrated planning methods, prototypes have to be developed and monitored to obtain reliable facts and ensure that office buildings help mitigate climate change.

Prof. Claus Steffan
TU Berlin

I
Climate Analysis
The Climate of Hashtgerd New Town

1 Introduction

The first step in adjusting the scheme to the environment is to survey the climatic elements of the given location, where each element has a different impact and requires a different solution (Olgyay, 1963). The climatic region alone does not provide sufficient information for a climatic design, and more detailed climate data is needed to illustrate the climatic conditions accurately.

For a detailed analysis of a given climate, hourly or at least daily climate data must be taken into consideration. In order to understand the climate conditions for an energy-efficient design, various climate factors affecting the thermal behavior of a building, including the dry-bulb and wet-bulb temperature, the relative humidity, the wind speed and direction as well as direct and diffuse solar radiation are of importance.

Due to the fact that hourly or even daily data for different climate factors includes thousands of numbers, tools which illustrate the climate data graphically are indispensable. The tools are more informative and helpful for understanding the climate if they illustrate the climate factors in relation to each other and in relation to the required conditions, such as the thermal comfort zones. Some of the most useful tools are the building's bio-climatic chart, the psychrometric chart, wind wheels, sun charts and sun shading charts.

As the New Generation Office Building, as an energy-efficient office building, is designed in Hashtgerd New Town, the climatic conditions of this particular city had to be studied. Due to the fact that the main objective of the pilot building is energy efficiency, a more accurate and detailed survey of the city's climate was required.

There are many approaches for classifying climate zones, of which W. Köppen's is the most widely accepted. According to the Köppen classification, Iran is divided into the following four regions:
1. Cold climate
2. Temperate and humid climate
3. Warm and humid climate
4. Warm and dry climate (Kasmaei, 2004)

Hashtgerd New Town is located in the warm and dry climate region; however, very close to the cold climate region. Therefore, the city's climatic conditions are affected by the characteristics of both climate zones.

According to Olgyay's bioclimatic chart, Iran is divided into six winter and five summer climate regions. The winter climate regions are:
1. Very cold
2. Cold
3. Temperate and humid
4. Temperate and dry
5. Warm
6. Warm and humid

Summer climate regions are:
1. Temperate and humid
2. Warm and dry
3. Very warm and dry
4. Warm and humid
5. Very warm and humid

According to Olgyay's bioclimatic chart, the city of Hashtgert New Town is exposed to a cold winter climate and a warm and dry summer climate.

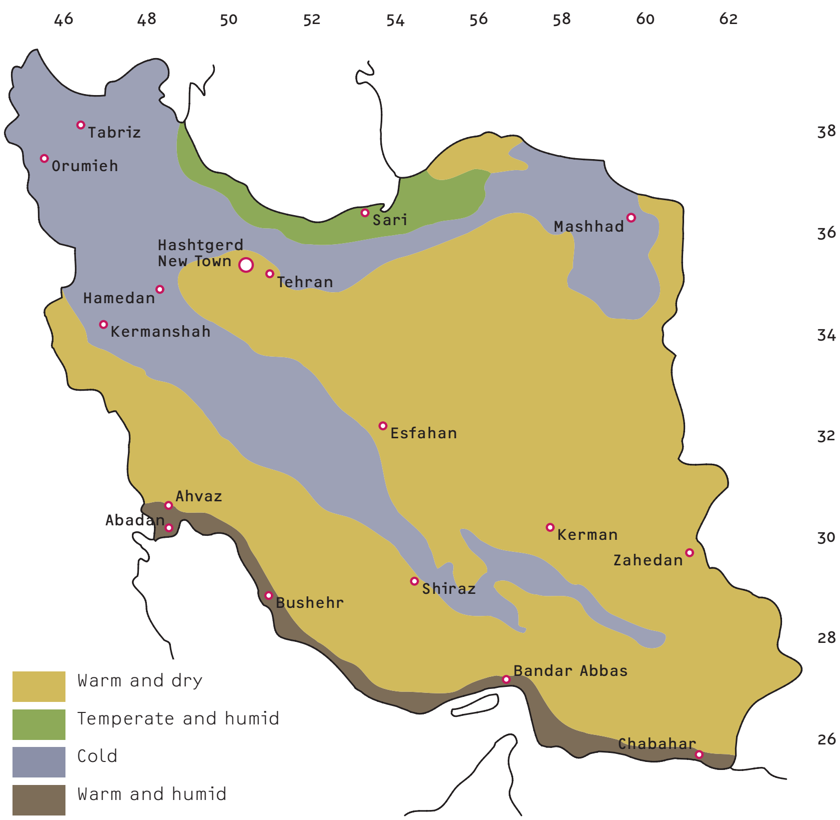


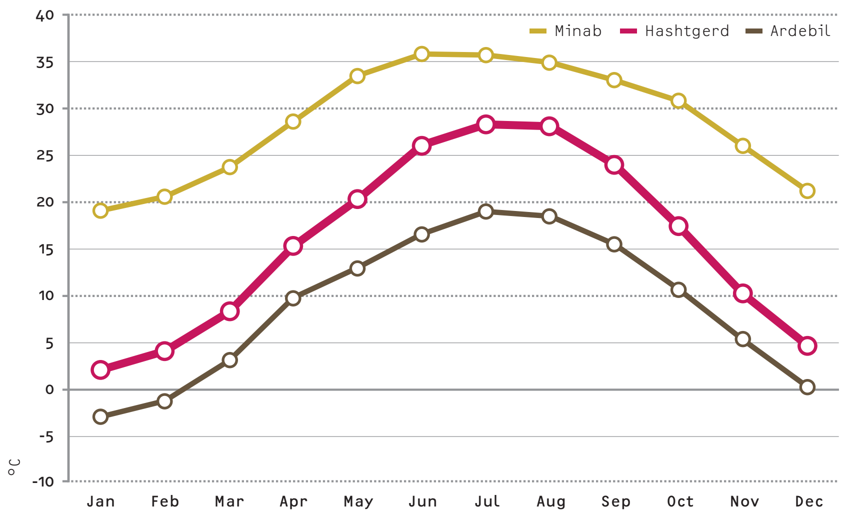
Fig. 1: Iran's climate regions according to the Köppen classification (Own drawing based on Kasmaei, 2004)

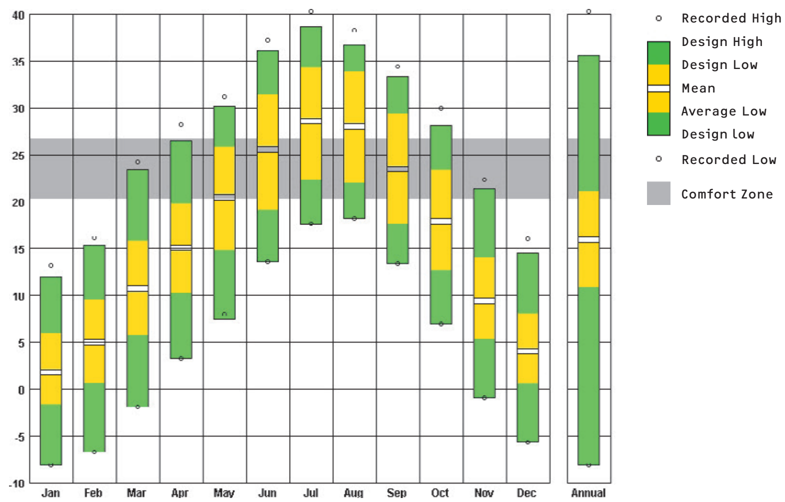
2 Climate Factors of Hashtgerd New Town

2.1 Air temperature

Figure 2 shows the monthly average dry-bulb temperature of the coldest and warmest cities in Iran to exemplify Iran's general temperature limits. It also includes the monthly mean air temperature of Hashtgerd New Town (based on data from Iran Meteorological Organization, 2009 and Meteonorm 6). According to this graph, the air temperature reaches neither of the temperature extremes throughout the year; however, it does show that Hashtgerd has a particularly cold winter and warm summer.

Figure 4 shows the (recorded, design and mean) monthly maximum and minimum as well as the monthly average air temperature of Hashtgerd New Town in relation to the comfort zone[1]. According to this diagram, the city's monthly average air temperature matches that of the comfort zone only during some months. The temperature is higher in the months July and August and considerably lower during the months October to April. The outside air temperature is only in line with the comfort temperature in May, June and September.





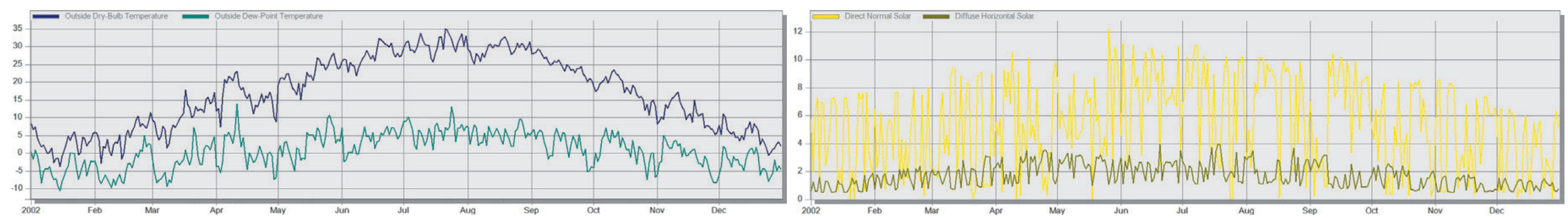


Fig. 2: Hashtgerd's and Iran's most extreme air temperature limits
Fig. 3a+b: Dry-bulb and wet-bulb temperature and diffuse and direct solar radiation in Hashtgerd New Town (Source of Weather Data: Meteonorm 6)

Fig. 4: Temperature range in Hashtgerd New Town (Source of Weather Data: Meteonorm 6)

Figure 3 shows the daily amount of dry-bulb and wet-bulb temperature as well as the direct and diffuse solar radiation in Hashtgerd New Town.

[1] The Comfort zone is based on ASHRAE Standard 55-2004 using the PMV Model.

2.2 Air humidity

Hashtgerd New Town experiences its highest relative humidity in January with 62% and the minimum in June and July with 22%. The following figure shows the dry-bulb temperature and relative humidity in Hashtgerd New Town in different months.

2.3 Wind

The following figures show the annual and monthly wind wheels for Hashtgerd New Town, which include the duration of wind occurrence, the wind direction, wind speed (maximum, minimum and average), air (and thus the wind) temperature and the relative humidity of the air (wind).

The wind blows throughout the year from different directions, more from the south-west, south and east. However, the wind clearly blows more from southern directions than from the north. The winds' temperature and humidity vary between 0 to 27°C and 30 to 70%, respectively, regardless of the wind's direction.

The monthly wind wheels show that the wind blows more frequently from the southwest to the northeast in summer months when natural ventilation is required.

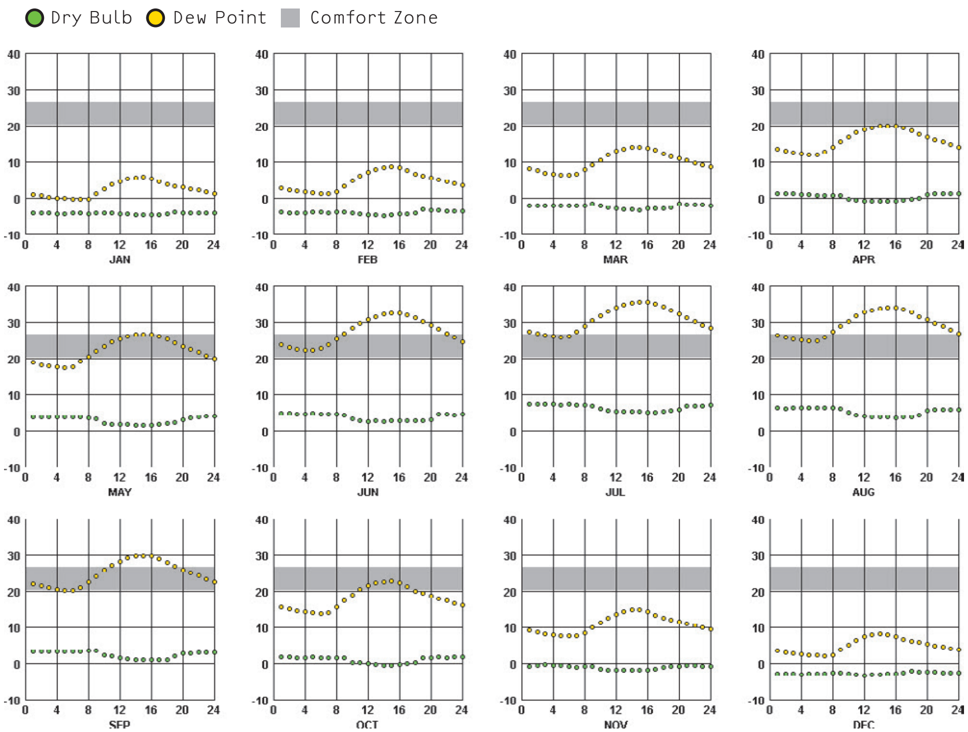


Fig. 5: Dry-bulb temperature and relative humidity in Hashtgerd New Town in different months (Source of Weather Data: Meteonorm 6)

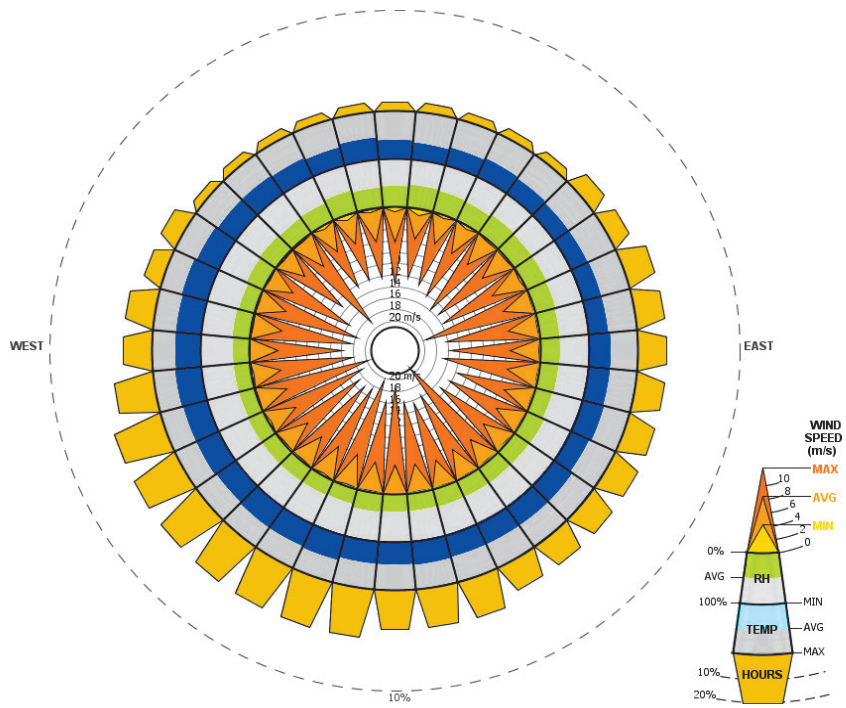


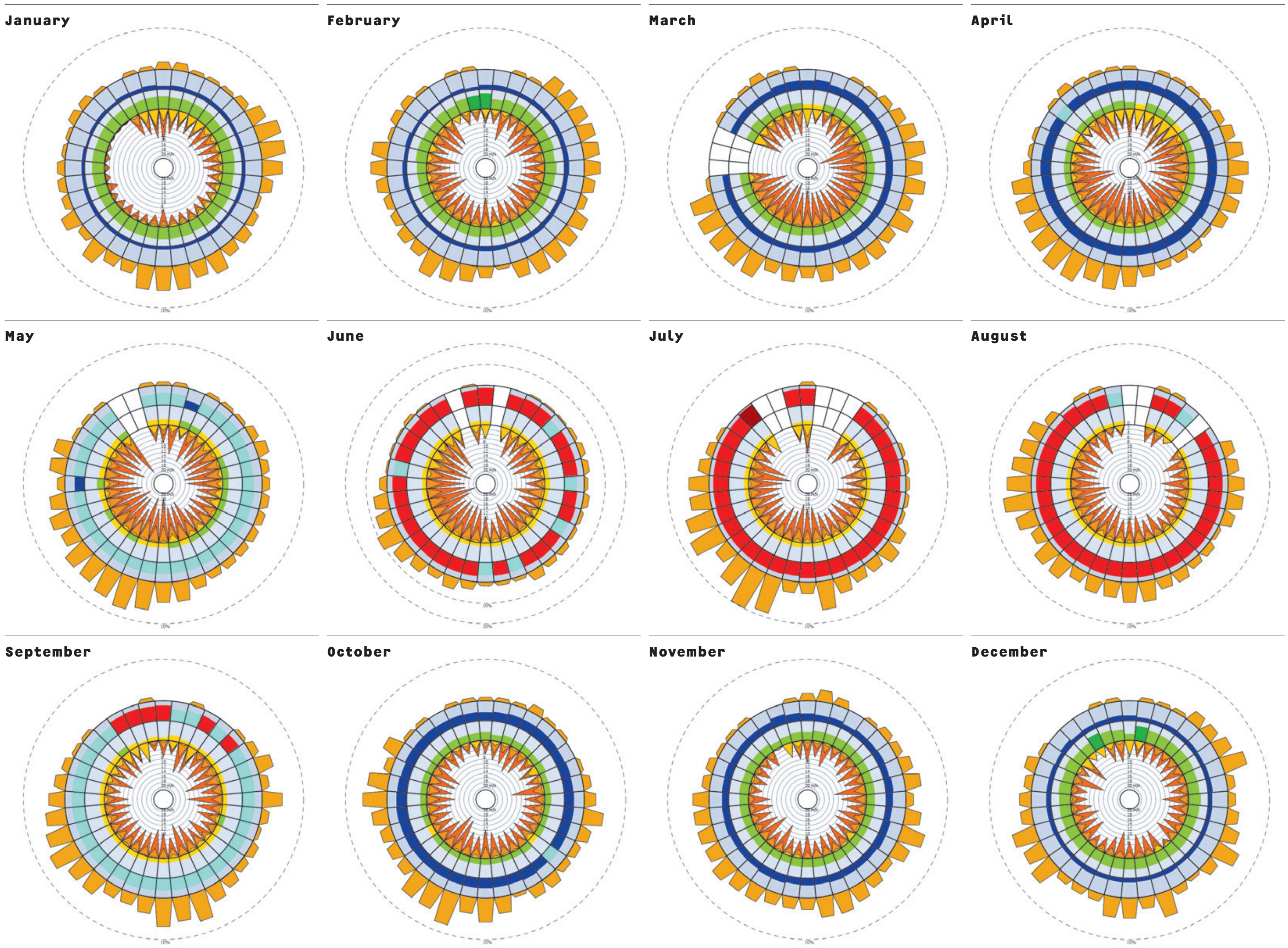
Fig. 6: Wind wheel for Hashtgerd New Town (Source of Weather Data: Meteonorm 6)

Temperature [°C]

< 0 | 0–22 | 22–24 | 24–38 | > 38

Relative Humdity [%]

< 30 | 30–70 | > 70



Tab. 1: Wind wheels for Hashtgerd New Town in different months (Source of Weather Data: Meteonorm 6)

Temperature [°C]

< 0 | 0–22 | 22–24 | 24–38 | > 38

Relative Humdity [%]

< 30 | 30–70 | > 70

3.1 Psychrometric chart analysis

The psychrometric analysis of climate data is the most appropriate method for preparing interior comfort conditions when using passive measures. The following graph shows the psychrometric chart for Hashtgerd New Town based on the relevant dry-bulb temperature.

According to the psychrometric charts, both heating and cooling are necessary to achieve comfortable thermal conditions. For approximately 58% of the year, the temperature is below that of the comfort zone and heating is required; for only 22% of the year, the air temperature is higher than that of the comfort zone. The charts also show that the city's relative humidity is very low, especially in warm periods.

The annual time share and the hours of possible ways to supply comfortable conditions in buildings in Hashtgerd New Town are listed in table 2.

No.	Strategy		Time/Year
1	**Comfort**	19.4%	1,698 h
2	**Sun shading of windows**	18.9%	1,656 h
3	**High thermal mass**	9.7%	853 h
4	**High thermal mass/night flushing**	9.8%	861 h
5	**Direct evaporative cooling**	21.6%	1,890 h
6	**Two-stage evaporative cooling**	21.7%	1,897 h
7	**Natural ventilation cooling**	5.9%	516 h
8	**Fan-forced ventilation cooling**	7.1%	623 h
9	**Internal heat gain**	21.3%	1,867 h
10	**Passive solar direct gain (low mass)**	11.9%	1,039 h
11	**Passive solar direct gain (high mass)**	14.1%	1,234 h
12	**Wind protection**	0.5%	45 h
13	**Humidification**	0%	0 h
14	**Dehumidification**	0%	0 h
15	**Cooling, added dehumidification if needed**	0%	0 h
16	**Heating, add humidification if needed**	28.9%	2, 534 h

Tab. 2: Annual number of hours for the application of different design strategies in Hashtgerd New Town (Source of Weather Data: Meteonorm 6)

Thus, the following conclusions regarding the building's conditioning strategies can be made:

Heating

- Passive (direct) solar heat gain is very important for heating buildings in Hashtgerd New Town and can be used for about 24.8% of the year.
- Internal heat gains can supply comfortable conditions for 20% of the year.
- The buildings in Hashtgerd New Town must be protected against cold winter winds for 1.9% of the year.

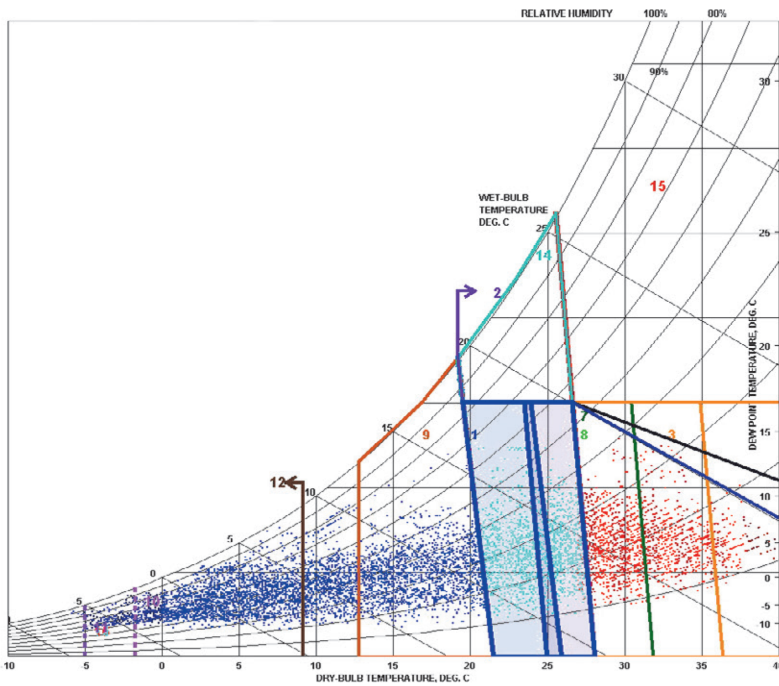
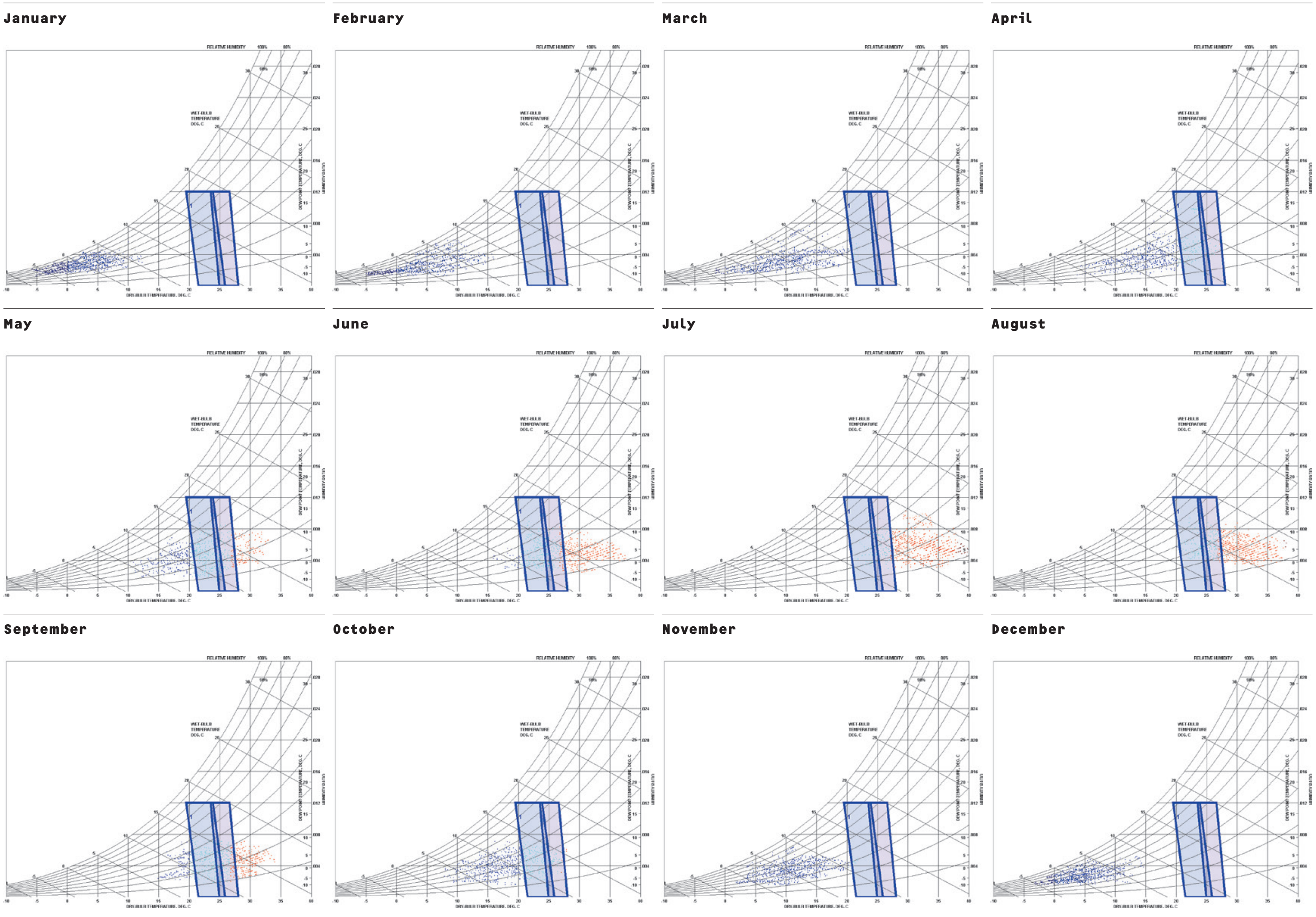


Fig. 7: Psychrometric chart for Hashtgerd New Town (Source of Weather Data: Meteonorm 6)

The need for heating and cooling depends on the building's architecture and materials. But if only the climatic conditions of Hashtegrd New Town and the psychrometric charts of different months are considered, heating is required in January, February, March, April, October, November and December, cooling in June, July and August. Both heating and cooling are required in May and September.

Cooling

- According to the psychrometric chart of Hashtgerd New Town, shading must be used at windows during the day for 17.2% of the year in order to prevent solar radiation from entering the indoor space and overheating the building.
- Natural ventilation can be used for about 7.4% of the year.



Tab. 3: Psychrometric charts for Hashtgerd New Town in different months (Source of Weather Data: Meteonorm 6)

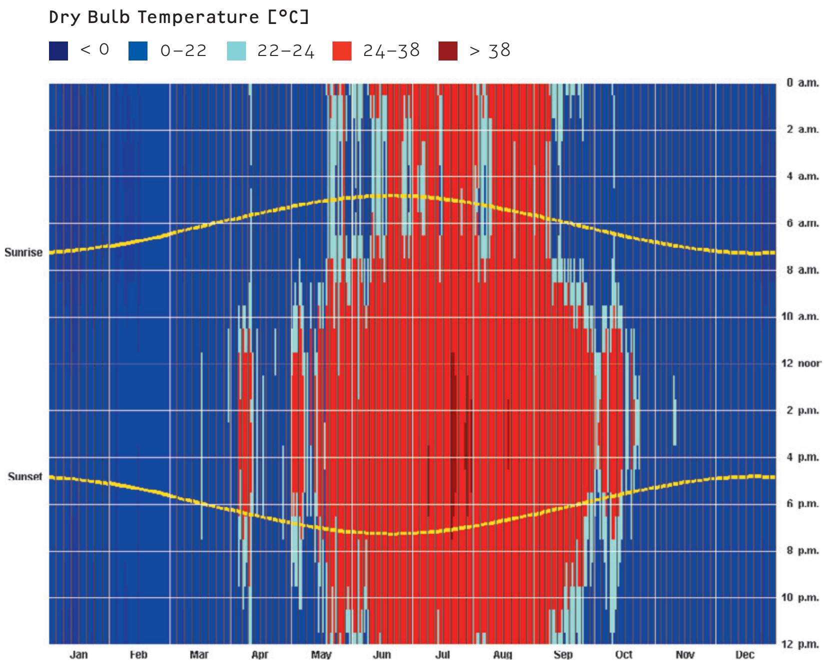
- Because of the low relative humidity in Hashtgerd New Town, passive and active evaporative cooling can be used for cooling buildings in summer. Evaporative cooling can be used for 20.3% of the year, which is almost the total period cooling is actually required. Therefore, all cooling needs in Hashtgerd New Town can be covered by evaporative cooling.
- Based on the psychrometric chart, the capacity of building mass and materials to store heat for cooling purposes is vital in Hashtgerd New Town. Cooling through thermal mass can be used for 7.9% of the year.

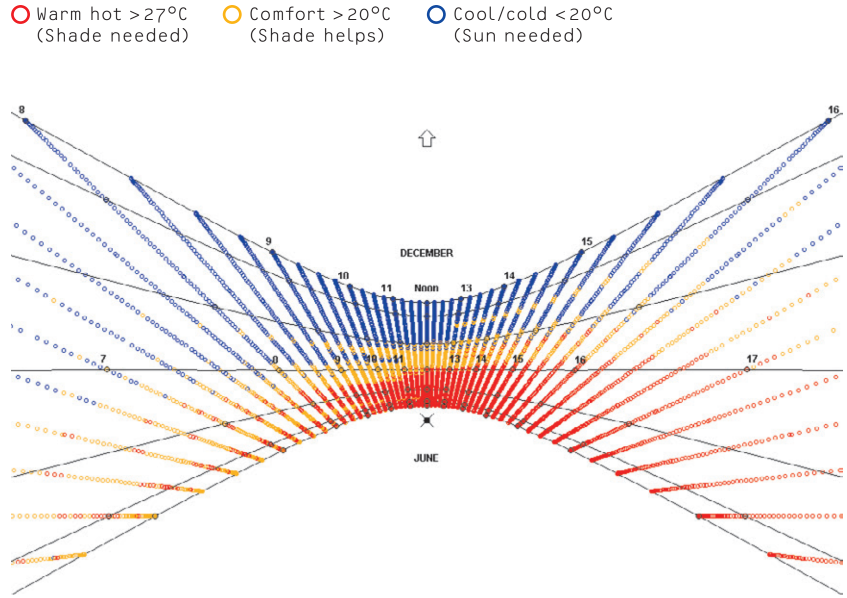
3.2 Temperature timetable plot

Figure 8 shows the real-time plot of the dry-bulb air temperature during different months and times of the day (including the time of sunrise and sunset) for Hashtgerd New Town. Based on this figure, the air temperature is below the comfort zone in January, February, March, November and December. Therefore, the internal and external heat gain must be as high as possible and heat loss as low as possible during these months.

The diagram also shows that the air temperature around noon in July and August is between 27 and 38 °C. Cooling is required during this period; the internal and external heat gains must be kept as low as possible.

According to this real-time plot, the air temperature is generally lower during the first half of the day than the second throughout the year. In winter, more solar heat gain is required in the morning than in the afternoon; thus, the building is best turned from true south to several degrees east of south.





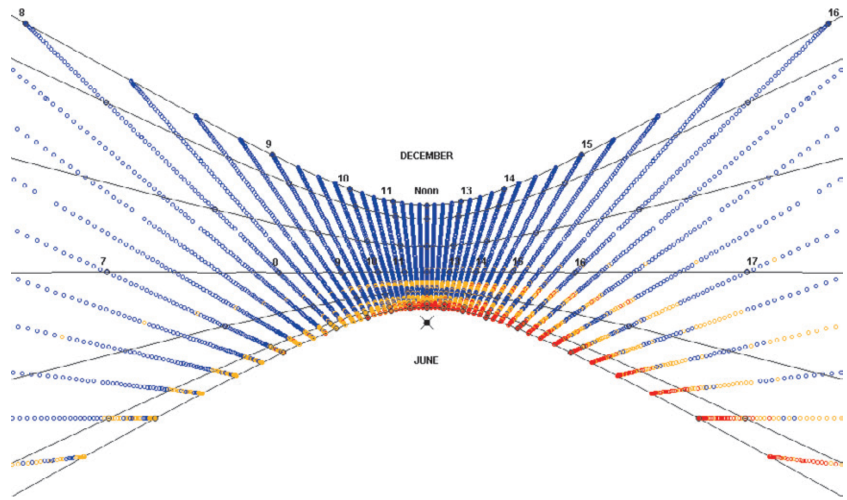


Fig. 8: Real-time plot for Hashtgerd New Town (Source of Weather Data: Meteonorm 6)

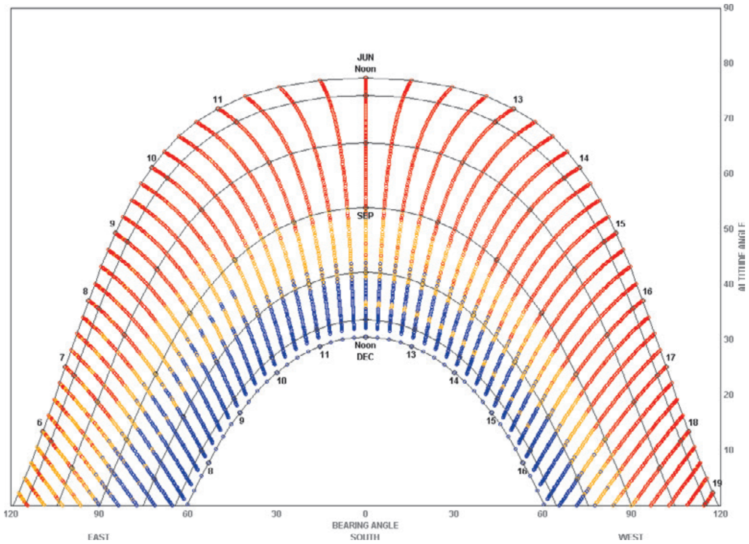
Fig. 9: Sun chart of Hashtgerd New Town (June 21 to December 21)
Fig. 10: Sun chart of Hashtgerd New Town (December 21 to June 21)
(Source of Weather Data: Meteonorm 6)

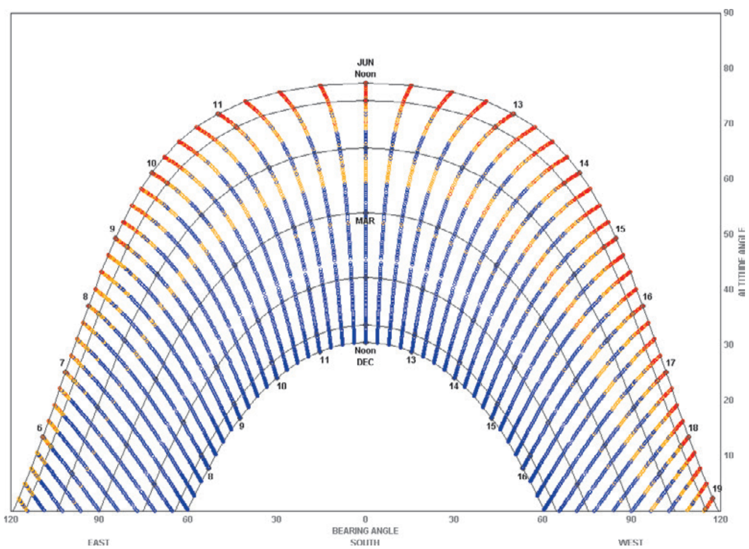
3.3 Sun chart and sun shading chart

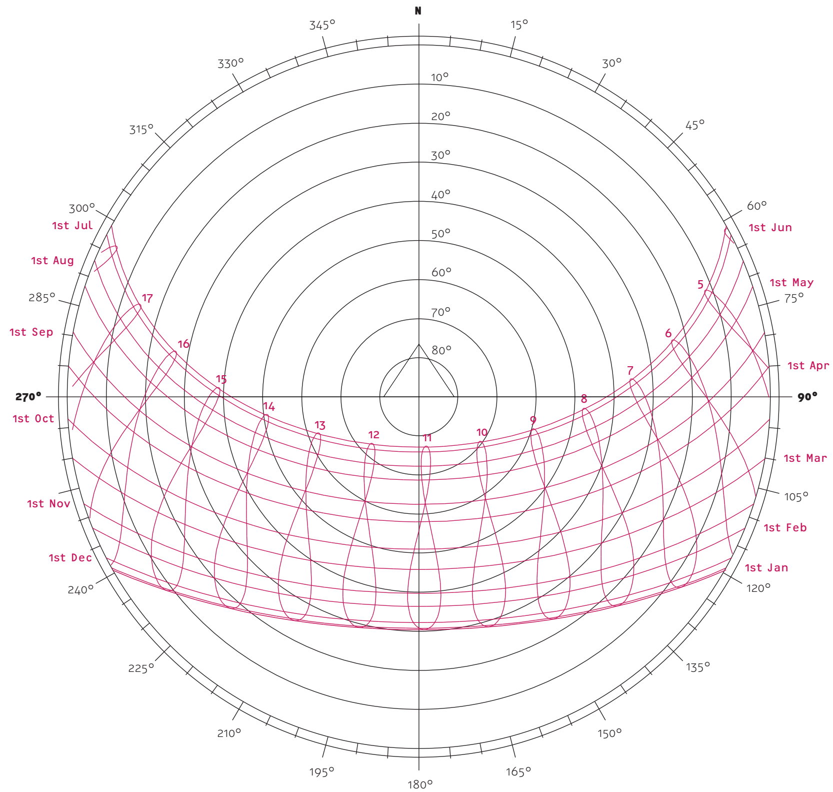
Throughout the period during which the air temperature is greater than the lower temperature limit of the comfort zone, no solar radiation is required and glazed surfaces must be shaded. This period applies for 17.2% of the year; so shading devices at windows are an important measure in Hashtgerd New Town. They are required during different times of the day and year. The ability to provide shade to windows only when needed is essential to reduce the cooling energy; however, the opportunity to make use of solar radiation should not be reduced.

The graphs above (Figure 9 and 10) show the sun chart of Hashtgerd New Town (from December 21 to June 21 and June 21 to December 21 respectively). They give an impression of when shading is required.

Figures 11 and 12 show the sun shading chart of Hashtgerd New Town from 21 December to 21 June, and 21 June to 21 December.







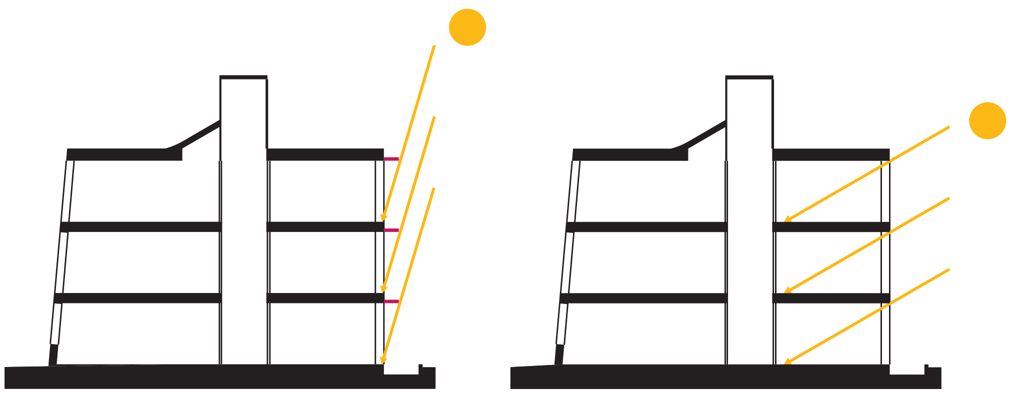


Fig. 11: Sun shading chart of Hashtgerd New Town (June 21 to December 21)
Fig. 12: Sun shading chart of Hashtgerd New Town (December 21 to June 21)
(Source of Weather Data: Meteonorm 6)

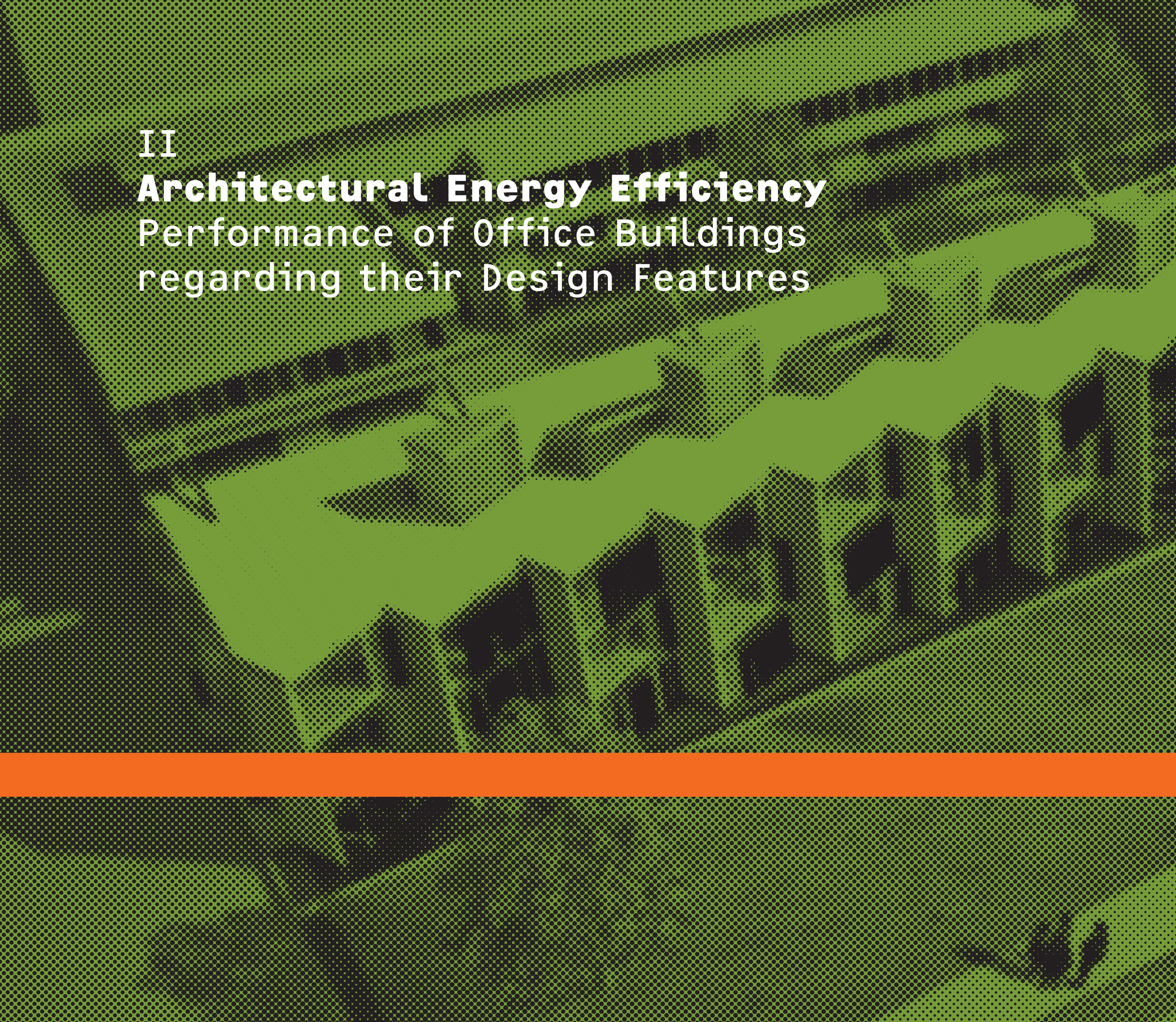
Fig. 13: Sun path diagram of Hashtgerd New Town
Fig. 14: Solar Altitude in summer and winter

The sun path diagram (Figure 13) shows the solar altitude and solar azimuth in Hashtgerd throughout the year.

Based on the information of the sun path diagram, Figure 14 shows the solar altitude in Hashtgerd for summer and winter solstice. The highest altitude at summer solstice in Hashtgerd is about 78°, and thus very high in summer. As a result, small horizontal shading devices, such as overhangs or horizontal louvers, can cover the shading requirements at south-facing windows. The solar rays hit the horizontal surfaces almost vertically at noon on a summer's day; horizontal surfaces, such as roofs, therefore receive a great amount of solar energy in summer, especially around midday.

The sun's maximum altitude on December 21 is only 30.54°. Therefore, vertical surfaces, particularly south-facing surfaces, receive sufficient solar heat gain receive sufficient solar heat gain for passive heating purposes in winter.

II
Architectural Energy Efficiency
Performance of Office Buildings regarding their Design Features



1 Architectural Energy Efficiency

Energy saving in buildings through cost and energy-intensive measures, such as the application of additional building materials and technologies, is only possible with a great consumption of resources and CO_2 emissions for their production. These extras include, for example, the use of insulation material to increase the thermal resistance of the building envelope, the installation of energy-efficient heating, cooling, ventilation and lighting equipment and the application of renewable energy systems to supply a proportion of the building's energy demand. Decreasing the energy demand of buildings through these measures leads to an increase of building investment costs. For low energy buildings, the investment costs, including user costs and governmental subsidies, are generally high, and construction is not always economically viable in consideration of the national capital in the present economic conditions of most countries. For these reasons, it is first of all necessary to apply cost and resource-efficient measures to save energy in buildings and then make use of additional cost and energy-intensive measures by improving the thermal envelope, the HVAC system or by installing energy generating systems.

One of the most cost effective and ecological methods of energy saving in buildings is the reduction of energy requirements through climate responsive architecture. Due to the fact that energy saving through the optimization of architecture is not only cost-neutral, resource-efficient and carbon-neutral but also has a very high energy-saving potential, the first and most important strategy to save energy should be an optimized and climate responsive design. Energy saving through optimized architectural design is economically and ecologically sustainable.

The development of building simulation science in the last decades has made it easier to study the energy performance of buildings. Tools have made it possible to predict the complex behavior of buildings regarding the climate. Except for the comparison of different building typologies to find the most efficient, there are no other methods to achieve energy savings through the architectural design, which can be applied by a variety of building types and climates. Therefore, in order to encourage the optimization of architectural design, it is necessary to improve these methods which represent strategies to significantly reduce the energy demand of buildings.

Architectural Energy Efficiency is a parametric method which separately studies the effects of various energy-related architectural factors on the energy demand of buildings by using dynamic energy simulations to find the, from an energy efficiency point of view, optimum value for each of these. The architectural factors include orientation, building elongation, building form, opening ratio in different orientations, sun shading, natural ventilation etc. This method of energy efficiency was originally developed by the author and introduced in the book "Climate and Energy Responsive Housing" in 2009.

The research process that led to the formulation of the Architectural Energy Efficiency method is based on a series of simulations carried out by a dynamic simulation software tool (DesignBuilder) to calculate the energy demands of a building with different variants for a single architectural feature. The simulations have served as a tool to study and understand the energy behavior of a building with changing parameters, such as orientation, opening ratio, elongation and others. The aim of the simulations is to find an optimum set of energy-related variables (building features) that result in the best and most efficient energy performance for a specific building type and climate.

This method of efficiency illustrates the effects different architectural features have on the various energy demands of buildings. The criteria are derived from the application of this method for a specific building occupation and climate, and can be applied in the design process of buildings, which leads to improvements of the energy performance and a reduction of resource consumption.

1.1 Optimizing criteria

As the architectural design affects the heating and cooling as well as the lighting energy demands of buildings, the optimum value of each factor must be based on these three aspects. The heating, cooling and lighting energy demands of buildings all behave very differently. For example, the cooling and lighting energy demands act against each other, and architectural factors that decrease the lighting energy demand often increase the cooling energy demand. The same challenge applies to the heating and cooling energy demands. Therefore, these three energy demands together (i.e. the sum of heating, cooling and lighting energy) must also be applied as a criterion to study the building energy performance (behavior) and find the optimum value for each architectural feature. The heating, cooling and lighting energy demands should not only be applied individually as separate criteria. If the optimization of the building design were only based on one of these three demands, the outcome would most probably be an increase of the two others.

The heating energy demand refers to the energy that is consumed to heat the building and provide thermal comfort conditions in winter. The cooling energy demand refers to the amount of energy that is consumed to cool the building and produce comfortable conditions in summer. Natural gas is usually used for heating, electricity for cooling. In this study, the same fuels are applied as energy carriers for the heating and cooling of buildings. The lighting energy demand refers to the electricity demand to provide artificial lighting throughout the building and achieve the target illuminance if daylight is not available to produce the required light levels within a space.

The different energy carriers required for heating, cooling and lighting have different ecological and economic characteristics. As a large proportion of electricity is generated from fossil fuels and the efficiency of power plants is low (less than 60%), electricity must take on a more important role than gas in the analyses. Furthermore, electricity is more expensive and emits more greenhouse gases than natural gas. Therefore, from an ecological and economic point of view, the primary energy demand is a more meaningful criterion in the analyses. The primary energy consumption refers to the direct use of energy at the source or the supply of crude energy which has not yet been subjected to any conversion or transformation process (IEA, 2013).

For this reason, each architecture-related energy demand, namely heating, cooling and lighting, has a multiple factor, such as the CO_2 emission factor, the primary energy factor or price factor. The criteria for selecting the best variant can therefore not only be based on the total energy demand, but should also consider the primary energy demand, the CO_2 emissions, energy costs (for heating, cooling and lighting), life cycle costs, etc. The application of these findings to the architectural design of buildings minimizes the energy demand, the CO_2 emissions and energy costs of the building, does not, however, affect the initial building costs.

This study considers the heating, cooling and lighting energy demands separately, the total energy demand (the sum of heating, cooling and lighting) and the total primary energy demand in office buildings. As this study is applied to office buildings in Iran, the primary energy factors of Iran are used, where the primary energy factor is 1.1 for natural gas and 3.6 for electricity.

1.2 Conclusion

The advantages of energy saving through optimizing the architectural design are not only the improvement of the building's energy performance, but also the fact that the energy saving is cost and resource-efficient. This means that the energy demand of a building will decrease without increasing the investment costs of the building and without consuming any resources and energy for the production of additional building materials. The cost and resource efficiency contributes towards the economic and ecological sustainability of a building during the full life cycle.

Architectural Energy Efficiency, as a method to optimize the architectural design, can be applied to different building types and climates to develop a set of energy saving guidelines for architects and building designers. These guidelines can then be applied in the design process (urban and architectural design stages), and lead to energy, cost and resource-efficient architecture.

If the criteria of the design guidelines is applied by architects at the design stage in defining the building's volume, form, orientation, window-to-wall ratio in different orientations, elongation, building height etc. the completed building will have a lower energy demand. The method is largely independent of building materials; although, the material characteristics of the thermal envelope influence the effectiveness of the energy saving. The application of these measures in the architectural design will minimize the ecological and economic burden of a building.

1.3 Application of Architectural Energy Efficiency in Iran

In the following study, Architectural Energy Efficiency is implemented in office buildings in the climatic conditions of the Tehran region to produce a set of criteria (Guidelines) for designing office buildings in this climate zone. As the orientation, the window-to-wall ratio and shading devices are the most important factors affecting the energy demand of buildings, these three aspects are focused on in the research. The application of the criteria in the design of the New Generation Office Building, as an energy-efficient pilot project, leads to energy savings of 50%, which is achieved solely through optimized architecture without the need for any additional materials or technologies.

The potential of energy saving through Architectural Energy Efficiency in Iran is very high due to the specific climate. The two main features of its continental climate, the high solar radiation and the low relative humidity, increase the potential of Architectural Energy Efficiency.

Because energy prices, even after the reduction of energy subsidies, are still relatively low in Iran and construction costs are high, cost-intensive measures for energy saving in buildings are not economically viable in Iran. However, due to the country's economic situation, all aspects of economic efficiency are crucial and there is great social interest in financially rewarding projects. For this reason, the method chosen to increase energy efficiency should be as cost effective as possible. Architectural Energy Efficiency is therefore very suitable for Iran from both an environmental and an economic point of view.

The orientation of a building has a significant impact on its energy demand. Among other architectural factors, it is one of the most important aspects regarding possible energy saving potentials. In order to study the effect of orientation on the heating, cooling and lighting energy demands of office buildings, a typical office building is simulated using different orientations and the climatic conditions of Hashtgerd New Town. The office building has predetermined characteristics in regard of building materials, elongation and window ratios. The simulation of the office building and the comparison of the energy demands show the energy-related behavior of office buildings according to different orientations. A simulation of the annual energy balance is made for the building in 10° steps. The orientation applies to the main façade with the biggest window area.

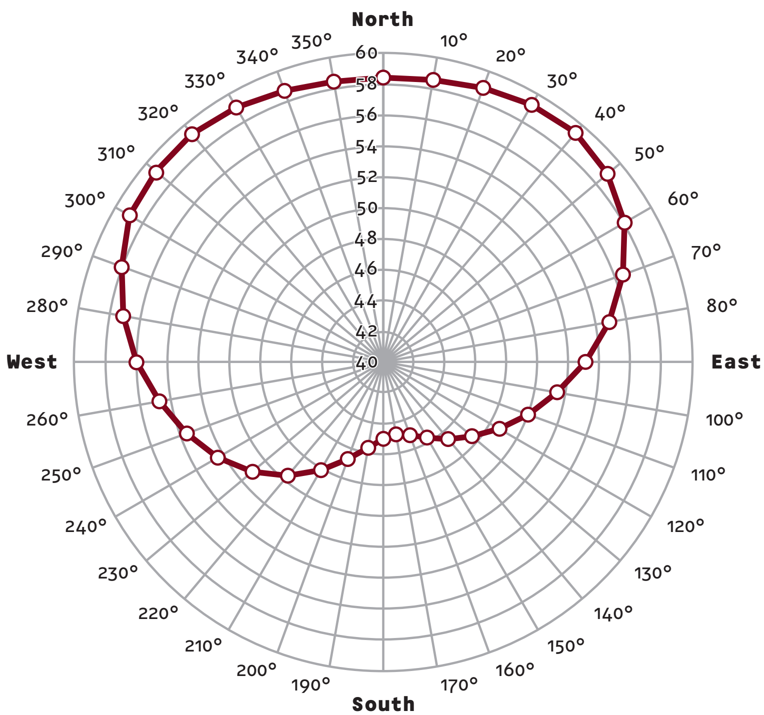


Fig. 15: Heating energy demand of an office building with different orientations (kWh/m²a)

2.1 Heating energy demand

The lowest heating energy demand occurs when the building faces almost south, at 170°. If the building is turned away from this orientation, either east or west, the heating energy demand increases. The building has its highest heating energy consumption at 40° and 320°. The heating energy demand of the office building varies by about 24% according to the different orientations.

2.2 Cooling energy demand

The cooling energy demand is at its lowest when the office building is set out in a north orientation. The highest cooling energy demand occurs when the building faces 110° and 260°. By turning the building from an east-west to a north–south direction, and vice versa, the cooling energy demand decreases. The described behavior is due to the sun's course throughout the day and year. In summer, the sun rises in the north-east, reaches its highest altitude in the south (which prevents extreme solar heat gains, which would then need to be removed) and sets in the north-west. On summer mornings (from sunrise to 10 a.m.), the sun moves from the north-east to the south-east of the building; the altitude is so low that the incident of solar radiation on these surfaces (walls) is much greater than on horizontal surfaces (roofs). Therefore, a building with a north-east, east or south-east orientation generates greater solar heat gains via the windows and the cooling energy demand is similarly high. For buildings with an orientation between south-west and north-west, the same phenomenon occurs on summer afternoons. At two points during the course of the sun, both in the south-east and the south-west (110 and 260°), the sun produces maximum solar heat gains in summer. The value of the building's cooling energy demand varies by about 28% according to the different orientations.

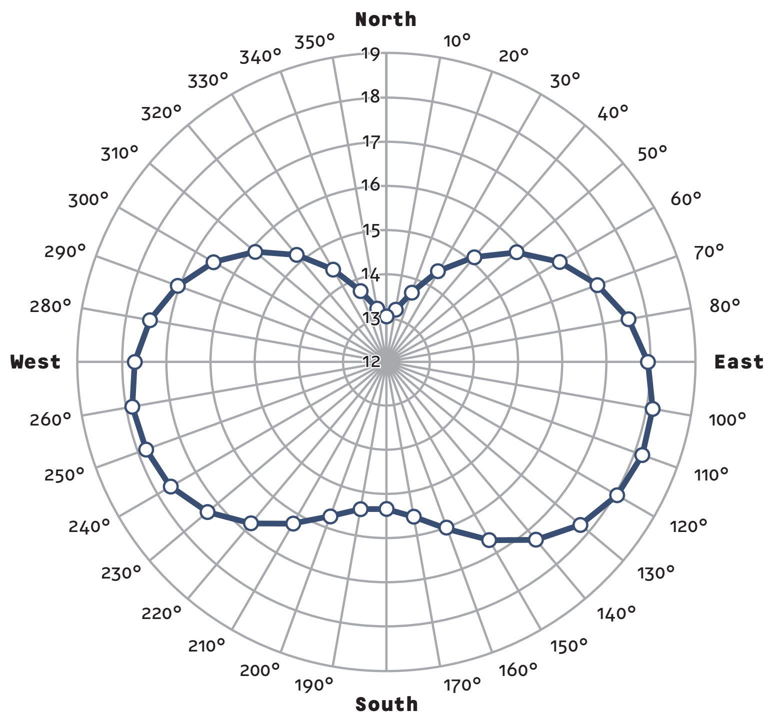


Fig. 16: Cooling energy demand of an office building with different orientations (kWh/m²a)

2.3 Lighting energy demand

The lighting energy demand in the office building differs from the heating and cooling demand. It has the lowest lighting energy demand when it faces 330° and the highest when it faces 170°. The energy demand for lighting varies by 11%.

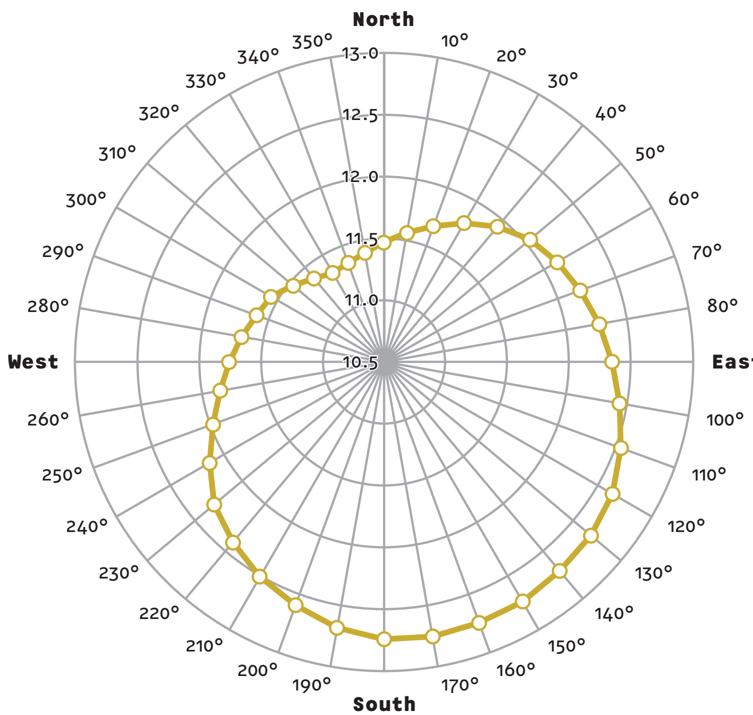


Fig. 17: Lighting energy demand of an office building with different orientations (kWh/m²a)

2.4 Comparison between heating, cooling and lighting energy demand

The following graph shows the extent of heating, cooling and lighting energy demands in the examined office building. It highlights that the orientation of the office building affects the lighting energy demand of the building very slightly compared to that of heating and cooling. The effect of the orientation is most significant in the case of the heating energy demand.

The office building has the lowest heating energy demand when it faces south. In the case of a south orientation, the cooling energy demand is low too. However, the cooling energy demand is not at its lowest with a south orientation. If the building is turned from the south slightly more towards the east or west, the energy demands behave in a similar way: they increase. However, the energy demands are not identical. In this climate and in office buildings, the amount of heating energy demand is always higher than that of both cooling and lighting. By way of comparison, the orientation has the biggest impact on the cooling energy demand.

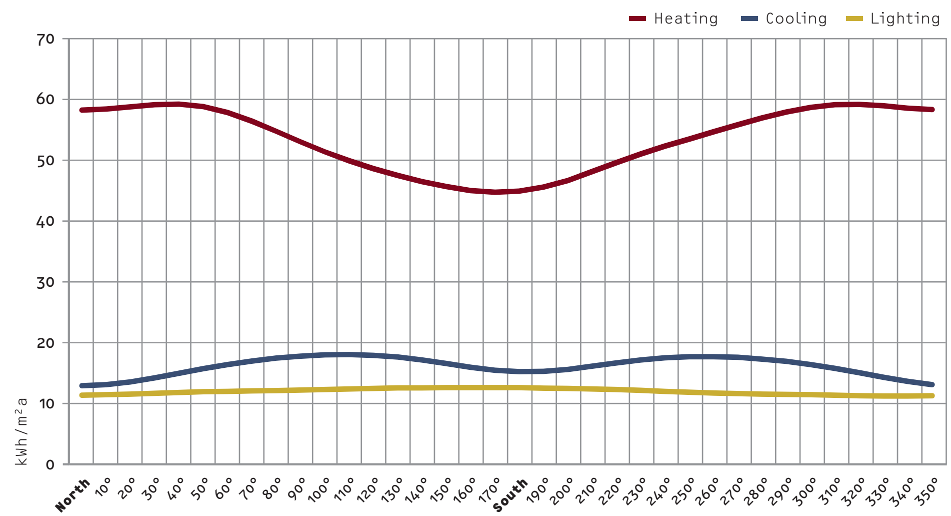


Fig. 18: Heating, cooling and lighting energy demand of an office building with different orientations (kWh/m²a)

2.6 Total energy demand

Because the heating energy demand of office buildings is greater in this climate than both the cooling and lighting energy demand, the total energy demand is similar to that of the heating demand. The south-facing office building has the lowest total energy demand. It increases when the building is turned north either east or westwards. The model building has its maximum energy demand at both 300° (northeast) and 50° (northwest). The main result of the simulation is that the optimum orientation of the building regarding its overall energy demand is south. According to these results, only the office building's perfect orientation in the climatic conditions of Hashtgerd New Town can save up to 16% energy in comparison to the highest possible value.

2.7 Primary energy demand

Similar to the total energy demand, the primary energy demand of office buildings with different orientations is at its lowest when facing either south or north. The low primary energy demand in the south is due to the low heating energy demand and the fairly low energy demand for cooling. The primary energy demand of office buildings with a north orientation is low because the building has a minimum cooling energy demand, which has a high primary energy factor.

The building reaches its maximum primary energy value at 270° (west) and 80° (10° north of due east). The reasons are the following: Firstly, in these two orientations, the building already has a relatively high heating energy demand; secondly, the high primary energy factor of the cooling energy amplifies the initially relatively high cooling energy demand. The difference between the highest and the lowest value is about 10%.

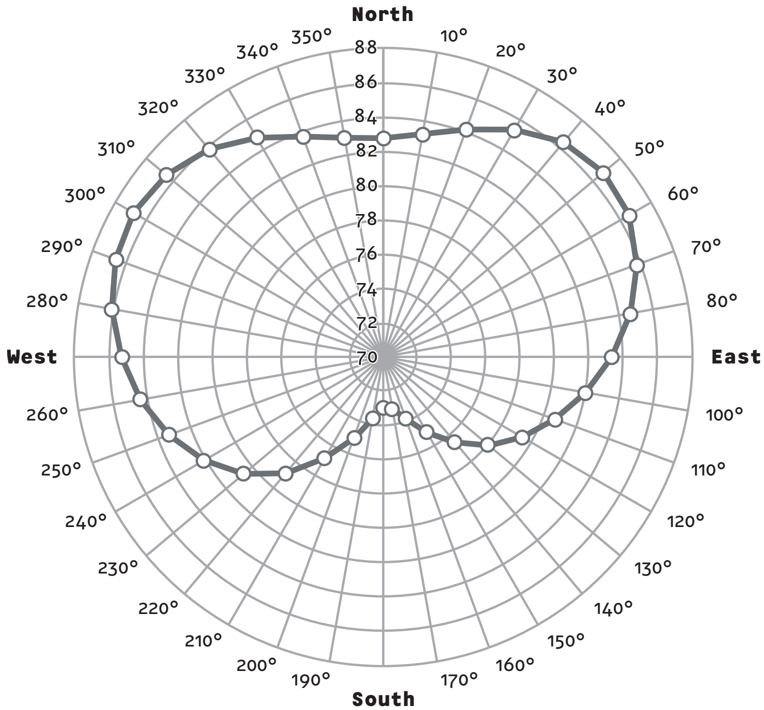


Fig. 19: Total energy demand of an office building with different orientations (kWh/m²a)

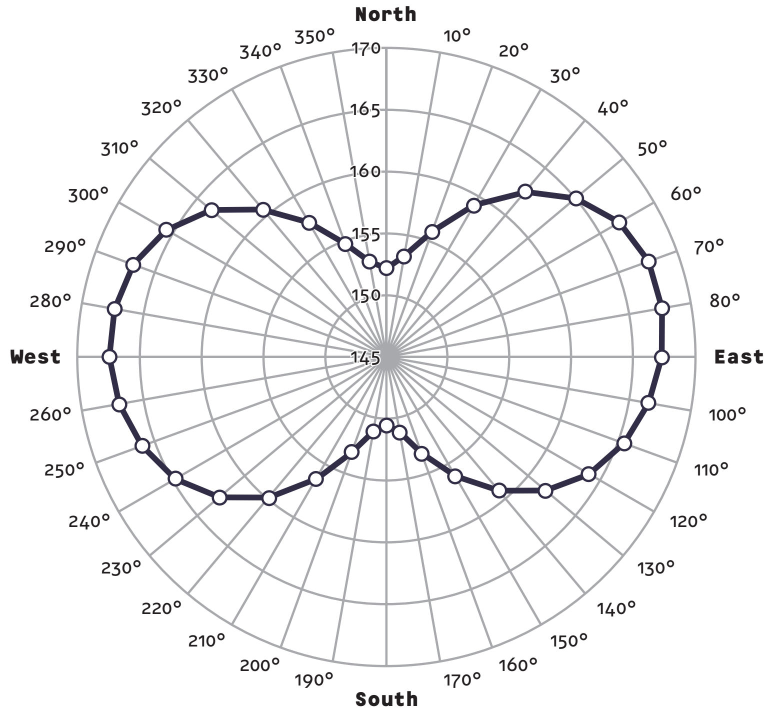


Fig. 20: Primary energy demand (heating, cooling and lighting) of an office building with different orientations (kWh/m²a)

2.8 Comparison of total energy demand and primary energy demand

The comparison between the total energy demand and the primary energy value has led to the following three major observations. Firstly, it can be noted that the primary energy demand is almost twice as high as the total energy demand. Secondly, the absolute differences in the set of primary energy values are greater than those of the total energy values. Finally, it has to be stated that, even though both demands differ in volume and absolute variance, their relative characteristics are extremely alike except in a north orientation. Both demands are at their lowest in a south orientation and at their highest in an east or west orientation. Nevertheless, the primary energy demand of a north-facing office building, compared to other orientations, is not as high as the total energy demand of a north-facing office building. Because the cooling energy demand of north-facing office buildings is low and the primary energy factor of electricity (cooling) is high, the primary energy demand of these buildings is also relatively small.

2.9 Conclusion

The optimization of the architectural design in regard of the building's orientation can lead to very high energy savings. The degree of this potential varies according to the climate conditions, the building utilization, the characteristics of the thermal envelope etc. This survey has shown that building orientation can affect the heating, cooling, lighting, the total as well as the primary energy demand of office buildings. Therefore choosing the ideal orientation for the building will reduce the total and primary energy consumption without using any additional materials or technologies. The energy saving potential of the perfect orientation in office buildings in this climate region is 16% and 10% for the total and primary energy demand respectively. These results show that it is possible to save large amounts of energy in office buildings solely through adjusting the building orientation. The analysis of the variations in the primary energy demand showed that this method can contribute significantly towards saving resources and minimizing CO_2 emissions. The choice of the perfect orientation requires no further materials or technologies, and thus has no effect on the life-cycle costs of the building.

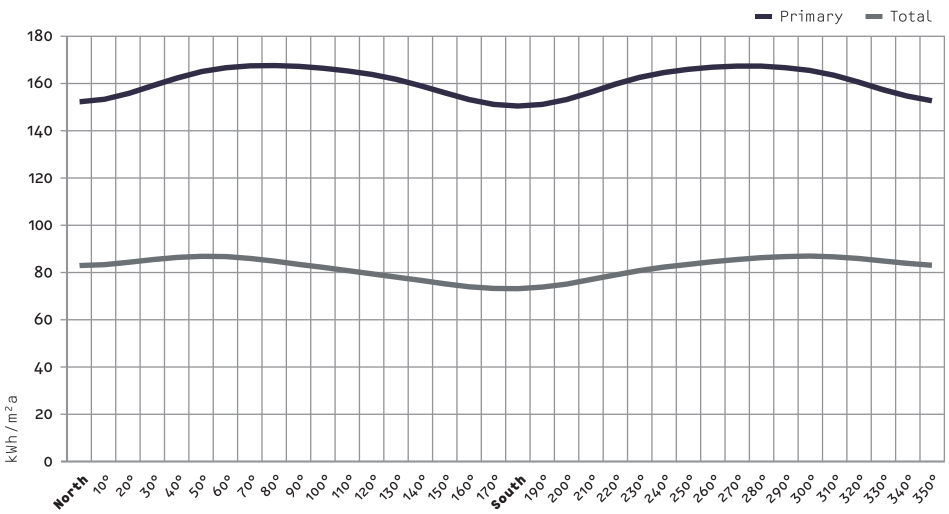


Fig. 21: Total and primary energy demand of an office building with different orientations

The proportion of window area on a building's façade has a significant effect on the energy demand and is one of the most important aspects in terms of energy efficiency achieved through architectural design.

Windows are the most crucial elements of a building from an energy point of view. In comparison to other components of the thermal envelope, these building elements often have a lower thermal resistance. Furthermore, windows, as a transparent component, provide solar heat gain as well as daylight. It is always beneficial to make use of daylight since it reduces the energy demand for artificial lighting. While solar heat gain is advantageous in the heating period, it is a disadvantage in the cooling period. Windows are, therefore, a vital constructional element with the most complex behavior in regard of the heating, cooling and lighting energy demand.

The properties of the windows, including the heat transfer coefficient (U-value) of both the glass and the frame, the solar heat gain coefficient (SHGC), the light transmission coefficient (T or τ) as well as the type of shading device and its shading factor, influence the way in which this building element affects the energy demand of the building. Therefore, it is necessary to determine a suitable window-to-wall ratio for a minimum energy demand which takes into consideration the climatic conditions, the building's main features as well as the characteristics of the windows and their shading devices.

In order to demonstrate the effect the window area has on the energy performance of office buildings in the climate conditions of Hashtgerd New Town and eventually to determine the perfect proportion of window area as a possibility to save energy, various simulations have been made using different window-to-wall ratios. This study is carried out for both a building without shading devices and a building with external blinds.

Since the amount of solar radiation incidence during the different times of day and year depends on the façade's orientation, a building must have different proportions of window area in different directions. In a second step, the study will establish the ideal window ratio for the individual orientations: the north, east and west-facing façades.

3.1 Window-to-wall ratios in all façades without shading devices

In order to find the ideal window-to-wall ratio in regard of energy efficiency, a building is simulated with different window areas. The building, which faces southwards and is elongated in the east-west axis, has the same window-to-wall ratio on all sides; there is no shading. The building is simulated under the same conditions (climate, construction and architecture) and all characteristics of the building are the same except the window area. The energy demands each for heating, cooling and lighting are the main focus of attention.

3.1.1 Heating energy demand

The office building with a 10% window-to-wall ratio has a higher heating energy demand than a building without any windows. This means that the building's heating energy demand rises by increasing the window area from 0 to 10%. This is due to the fact that the heat loss through windows in winter is greater in the case of a building with a 10% window-to-wall ratio than the solar heat gain compared to a building without any window area.

The heating energy demand of the office building decreases by increasing the window-to-wall ratio from 10 to 80%. The rise of the window-to-wall ratio from 80 to 100% has little effect on increasing the heating energy demand.

3.1.2 Cooling energy demand

Since the window area is increased equally on all façades, the solar heat gain in summer rises, in particular in the case of the east and west façades. Thus, the cooling energy demand of office buildings also goes up by increasing the window-to-wall ratio from 10 to 100%.

The cooling energy demand of office buildings decreases slightly by increasing the window-to-wall ratio from 0 to 10%, it then increases very slowly between 10 to 20% and rises more steadily after 20%.

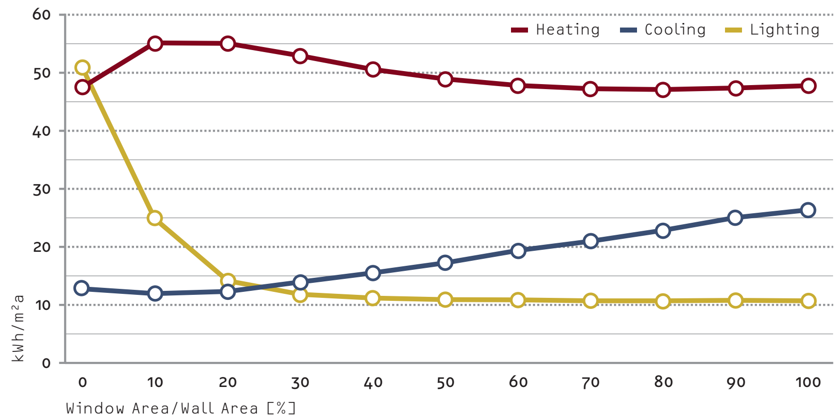


Fig. 22: Energy demands of office building without external shading devices with different window-to-wall ratios (kWh/m²a)

3.1.3 Lighting energy demand

The larger a building's window area, the more daylight is let in and the less artificial lighting is required. Thus, increasing the window area from no windows to an office building with fully-glazed façades increases the amount of daylight and decreases the amount of artificial light. In terms of lighting energy demand only, a 100% window-to-wall ratio would be best.

According to Figure 22: By increasing the window-to-wall ratio of the office building from 0 to 30%, the energy demand for lighting is reduced considerably. However, a window-to-wall ratio greater than 30% makes little difference.

Because the window area also affects the heating and cooling energy demands of the building, the window-to-wall ratio of all façades, especially the north, east and west-facing ones, should only be more than 30% if the better ratio has an advantageous effect on the overall energy demand and leads to a decrease of the total or primary energy demand of the building.

3.1.4 Total energy demand

By increasing the window-to-wall ratio from 0 to 50%, the total energy demand of office buildings without shading devices decreases. However, window-to-wall ratios higher than 50% lead to an increase of the total energy demand.

This shows that, if the windows are without external shading devices, the optimum window-to-wall ratio for office buildings is 50%.

3.1.5 Primary energy demand

The building's primary energy demand is influenced mainly by its lighting and cooling energy demands (due to the relatively high primary energy factor of electricity). By increasing the window-to-wall ratio from 0% to 30%, the primary energy demand decreases significantly due to the extreme fall in the lighting energy demand. Any window area greater than 30% increases the primary energy demand, which is mainly affected by an increase in the cooling energy demand.

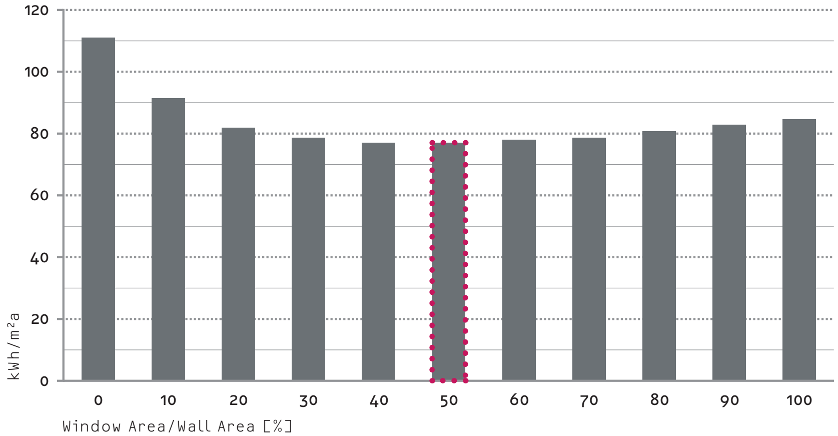


Fig. 23: Total energy demand of office building without external shading devices with different window-to-wall ratios (kWh/m²a)

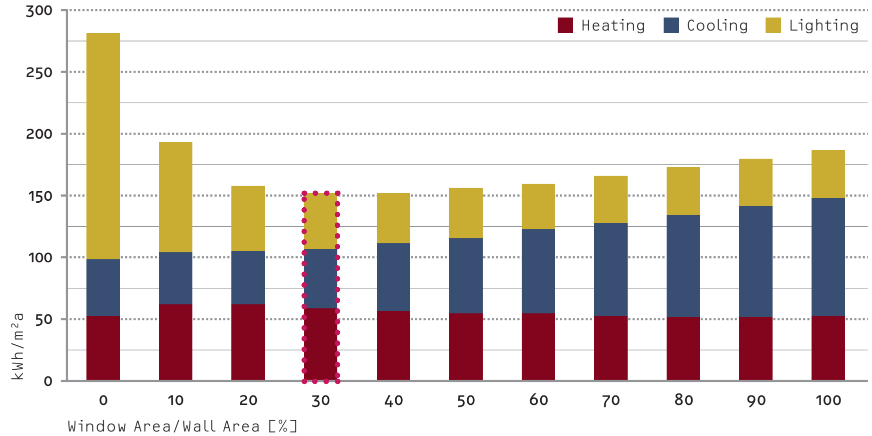
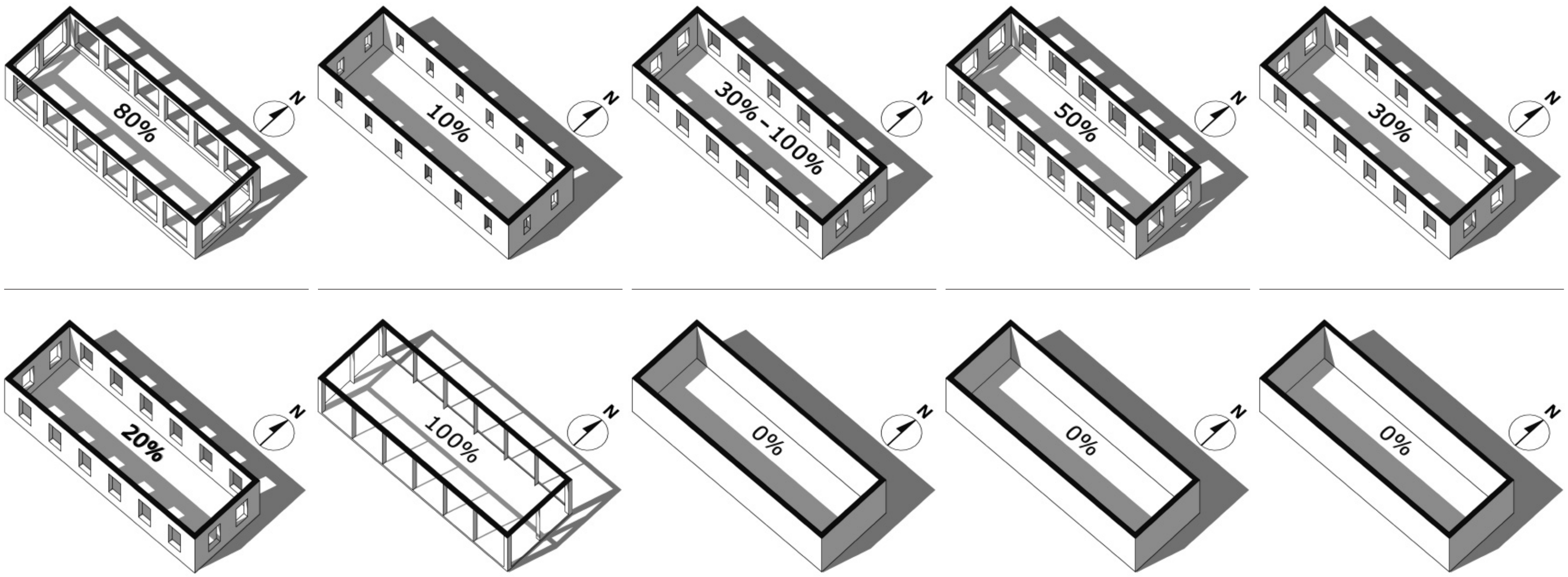


Fig. 24: Primary energy demand of office building without external shading devices with different window-to-wall ratios (kWh/m²a)

Table 4 presents the window-to-wall ratios for minimizing as well as maximizing the heating, cooling, lighting, total and primary energy demands in buildings without external shading. The table shows that the building has its maximum heating and cooling energy demand at a window-to-wall ratio of 20% and 100% respectively. The worst case for the lighting, total and primary energy demand is when the building has no windows at all.



	Heating Energy Demand	Cooling Energy Demand	Lighting Energy Demand	Total Energy Demand	Primary Energy Demand
Minimum Energy Demand	80%	10%	30% - 100%	50%	30%
Maximum Energy Demand	20%	100%	0%	0%	0%

Tab. 4: Window-to-wall ratios for the minimum and maximum energy demands in office buildings without shading devices

3.2 Window-to-wall ratios in façades with external blinds

Because the most suitable window area differs for buildings with and without shading devices and it is necessary to determine the impact of the windows on the energy balance of the building, a similar analysis is performed with external blinds at the windows. The results show that the energy performance of office buildings differs by changing the window area and adding external shading devices.

3.2.1 Heating energy demand

By increasing the window-to-wall ratio from 0 to 20%, the heating energy demand of office buildings increases by about 10kWh/m²a, which is a rise of about 20%. By increasing the window–to-wall ratio from 20 to 80%, the heating energy demand decreases by approximately 10kWh/m²a. A window–to-wall ratio between 80% and 100% has little impact on the reduction of the heating energy demand due to the fact that the heat loss in the heating period is greater than the solar heat gain that can be achieved through a window-to-wall ratio that is greater than 80%.

3.2.2 Cooling energy demand

The cooling energy demand of office buildings rises by increasing the window-to-wall ratio from 10 to 100%. The total variation is a little less than 10 kWh/m²a, which means a relative increase of slightly less than 50%.

3.2.3 Lighting energy demand

By increasing the window area, the lighting energy demand is reduced significantly. The reduction of lighting energy consumption is very high for a window-to-wall ratio between 0% and 40%. Above 40%, the lighting energy consumption decreases only very slightly. In comparison to the situation without windows, a 40 to 50% window-to-wall ratio means a low lighting energy demand. A window area greater than 50% makes little further difference.

3.2.4 Total energy demand

By increasing the window-to-wall ratio from 0 to 60% on all façades, the total energy demand of office buildings in Hashtgerd decreases noticeably by about 30%. Greater window areas, however, cause the total energy demand to rise again. Therefore, it can be concluded that, in the case of office buildings with external blinds, a window-to-wall ratio of about 60% on all façades is ideal regarding the building's total energy demand.

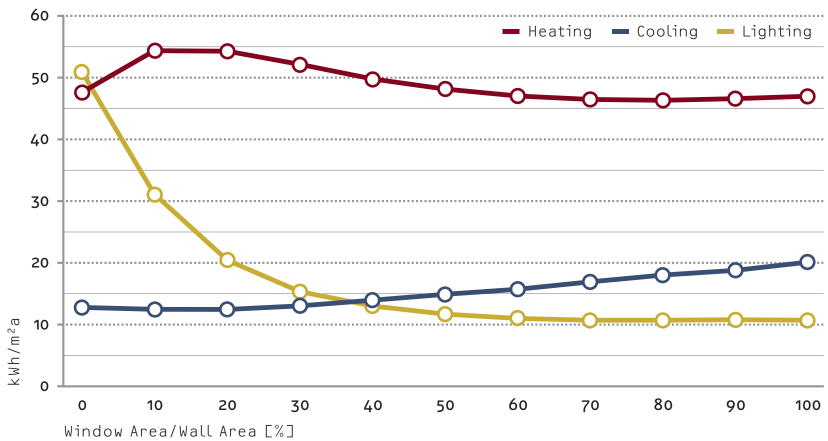


Fig. 25: Energy demands of office building with external blinds with different window-to-wall ratios (kWh/m²a)

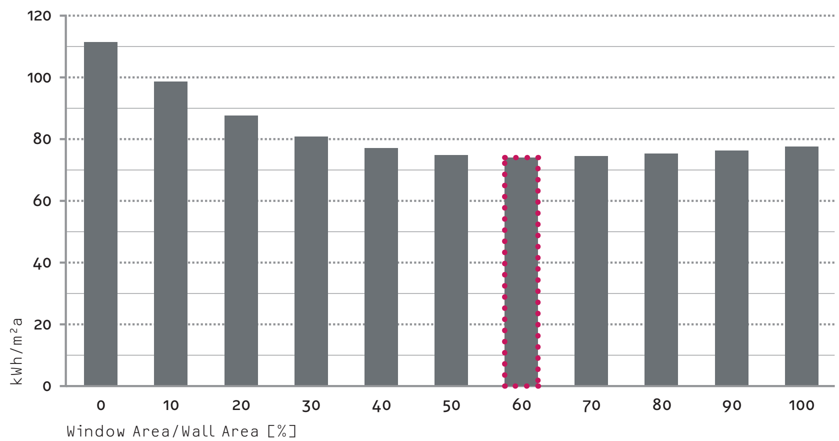
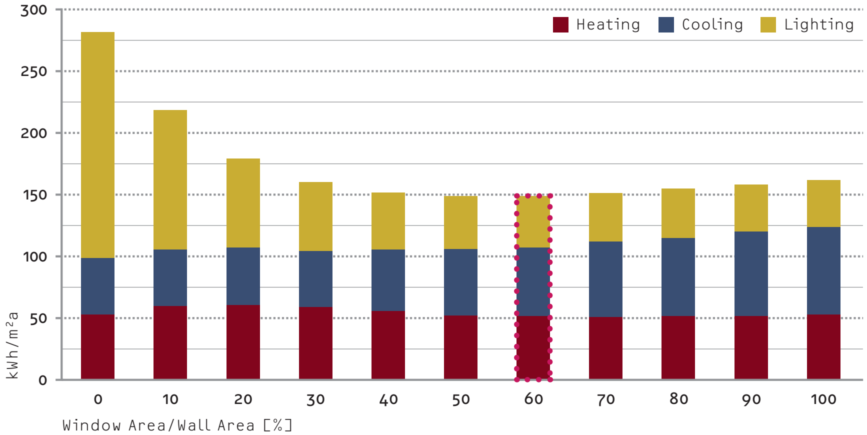


Fig. 26: Total energy demand of office building without external shading devices with different window-to-wall ratios (kWh/m²a)



3.2.5 Primary energy demand

The response of the building's primary energy demand to different window areas in buildings with external blinds is similar to that of the total energy demand. The primary energy demand decreases significantly in the case of a window-to-wall ratio between 0 and 60%, which is mainly due to the lighting energy demand's performance. Window-to-wall ratios greater than 60%, however, lead to a greater primary energy demand, which is the result of an increase in the energy demand for cooling.

Table 5 presents the most and the least suitable window-to-wall ratios for the heating, cooling, lighting, total and primary energy demands in buildings with external blinds. According to the table, the worst case, from an energy point of view for the heating and cooling energy demands, is 10% (up to 20%) and 100% respectively. Similar for buildings without

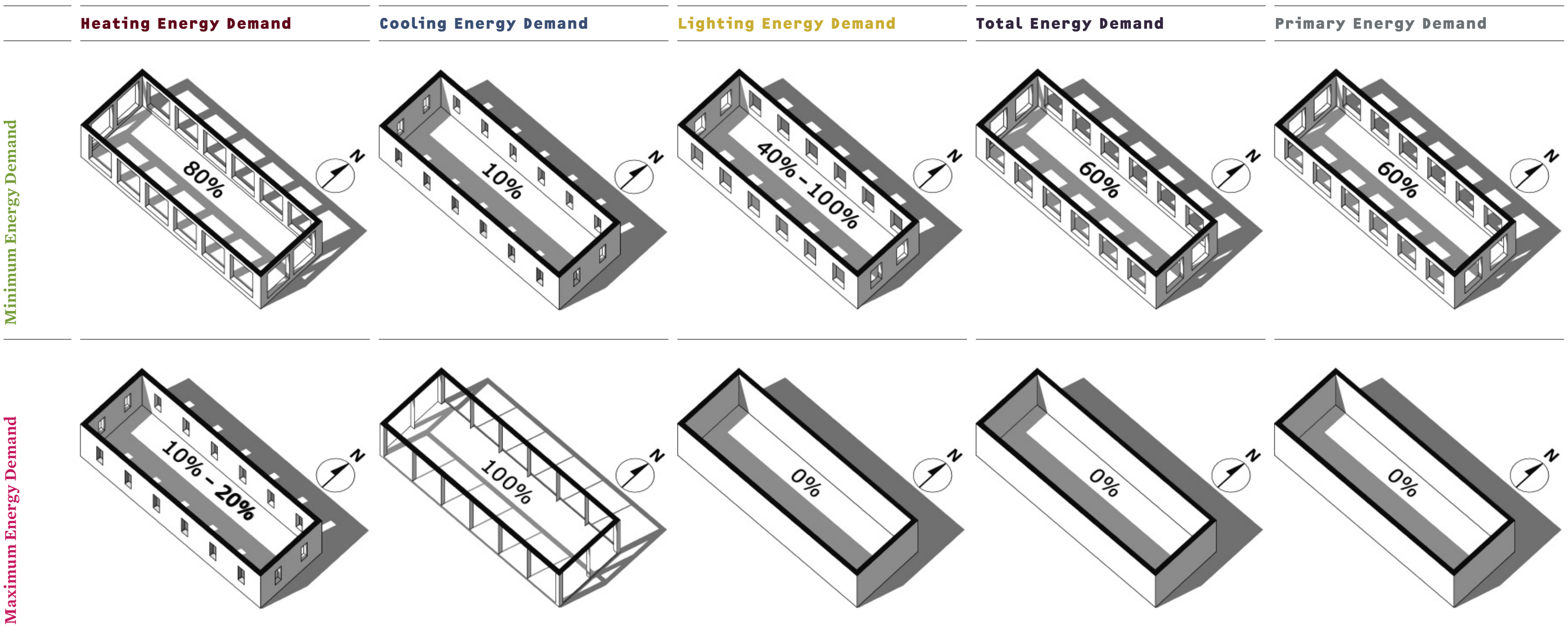


Fig. 27: Primary energy demand of office building with external blinds with different window-to-wall ratios (kWh/m²a)
Tab. 5: Window-to-wall ratios for the minimum and maximum energy demands in office buildings with external blinds

shading devices, the office building has its maximum lighting, total and primary energy demands when the building has no windows at all.

3.3 Comparison of window-to-wall ratios with and without external shading devices

To identify whether the influence of the window-to-wall ratio is stronger with or without external shading, the previous results are compared. The following figure displays the examined building's total energy demand both with and without external blinds. Both graphs have similar characteristics, but differ in form and the value of their lowest point. If external blinds are applied, the minimum total energy demand occurs at a window-to-wall ratio of 60%, which is 10% greater than for a building with no shading devices.

According to table 4 and 5, the ideal window-to-wall ratio for heating and cooling is approximately the same for buildings with and without shading devices. But buildings with external blinds require larger window areas to provide minimum lighting, total and primary energy demands. This fact is most obvious in the case of the primary energy demand.

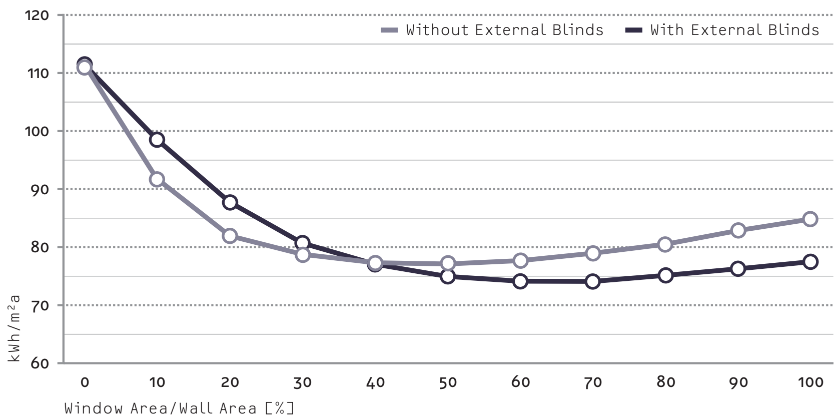


Fig. 28: Total energy demand of building with different window-to-wall ratios with and without external blinds (kWh/m²a)

3.4 Window-to-wall ratio of the north-facing façade (south, east and west with a 60% ratio)

As the previous simulations demonstrated, a 60% window-to-wall ratio in all directions is the best solution regarding the total energy demand of buildings. However, to determine the optimum window-to-wall ratio for each individual façade of the building, each individual envelope surface must also be analyzed. In the following, the window-to-wall ratios of all sides is kept at 60% while the one on the north side is varied.

The following graphs show how the building's energy demands change with different north-facing window-to-wall ratios.

3.4.1 Heating energy demand

The heating energy demand of the office building rises by increasing the north-facing window-to-wall ratio from 0 to 60%. Ratios higher than 60% would further increase the heating energy demand, which is why these ratios have been excluded from the diagram. There are two reasons for the increase of the heating energy demand: Due to the relatively high U-value of windows, in comparison to other wall components, the building's heat loss increases with a larger window area. At the same time, a larger window area cannot contribute any noticeable heat gains through solar radiation due to the sun's course throughout the day and year. The only time the north-facing side of the building is directly illuminated by the sun is either in the morning or evening in summer. Therefore, the north-facing windows can only generate very low solar heat gains in the heating period, which is via diffuse solar radiation.

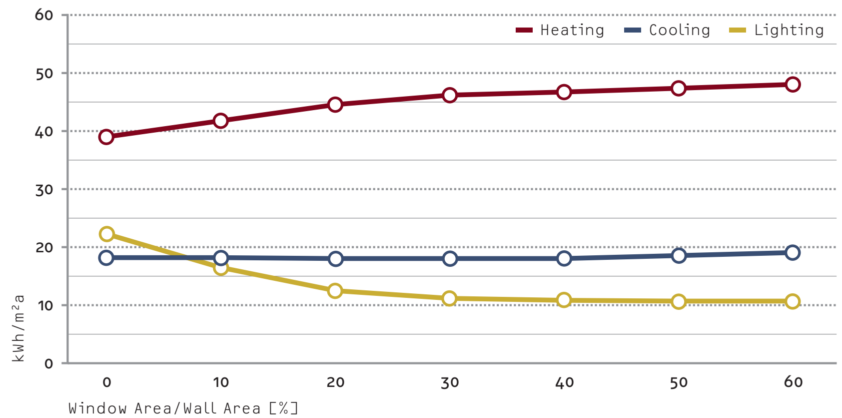


Fig. 29: Energy demands of office building with different north-facing window-to-wall ratios (kWh/m²a)

3.4.2 Cooling energy demand

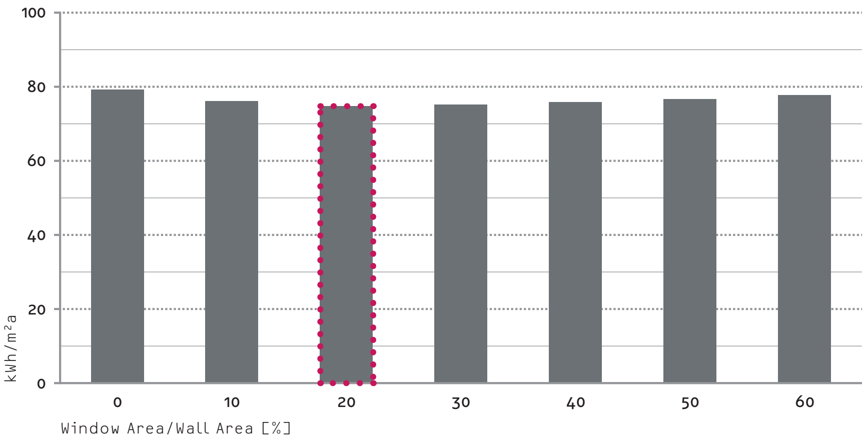
The building's cooling energy demand decreases marginally for a window-to-wall ratio of 0 to 20%. Ratios higher than 20% increase the cooling energy demand. However, the overall effect of the north-facing window area on the cooling energy demand is very slight.

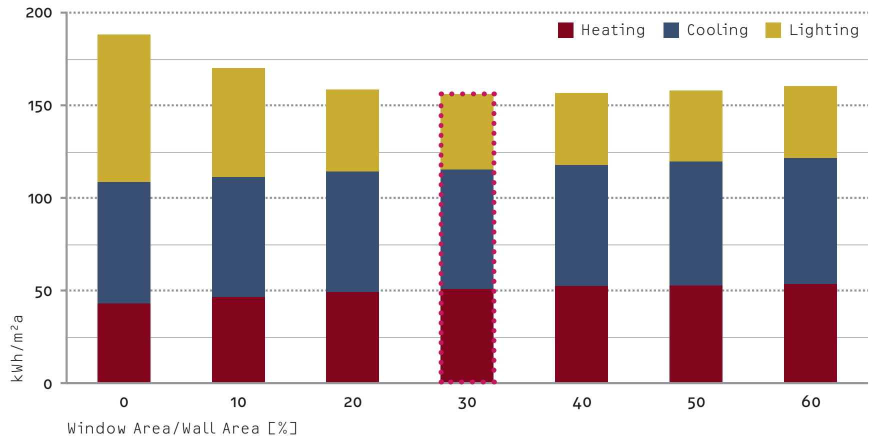
3.4.3 Lighting energy demand

Like in the previous simulations, the lighting energy demand in the case of north-facing windows decreases significantly by increasing the window-to-wall ratio from 0% upwards. So by increasing the size of the north-facing windows, the lighting energy demand of office buildings decreases. Beyond a window-to-wall ratio of 20 to 30%, the changes to the lighting energy demand are very slight. A further increase in window area will not contribute substantially to a further decrease in the lighting energy demand.

3.4.5 Primary energy demand

The primary energy demand decreases by increasing the window-to-wall ratio above 0%, which is due to the lighting energy demand's performance. This effect is intensified by the relatively high primary energy factor of electricity. The behavior of the primary energy demand is similar to that of the total energy demand. The minimum primary energy demand is met at a 30% window-to-wall ratio.





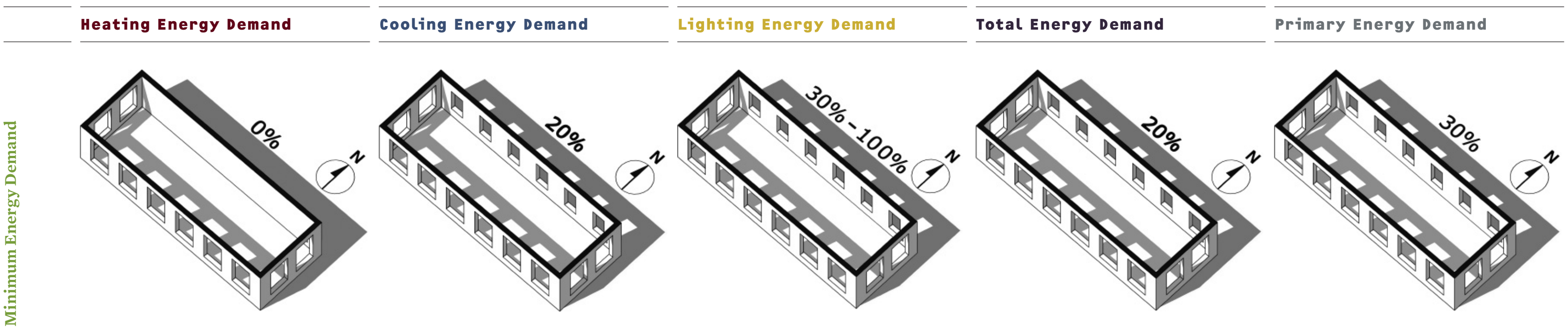


Fig. 30: Total energy demand of office building with different north-facing window-to-wall ratios (kWh/m²a)
Tab. 6: Different window-to-wall ratios of the north façade for minimum energy demands

Fig. 31: Primary energy demand of office building with different north-facing window-to-wall ratios (kWh/m²a)

3.4.4 Total energy demand

The total energy demand in office buildings decreases to its minimum by increasing the north-facing window-to-wall ratio from 0 to 20%. If the north-facing window area is raised beyond a 20% ratio, the total energy demand of office buildings increases. This shows that the optimum window area for a north-facing façade is a ratio between 20% and 30%.

Table 6 presents the most suitable window-to-wall ratios for the north-facing façade for the heating, cooling, lighting, total and primary energy demands in office buildings. According to the table, the best case, from an energy point of view for the heating, cooling, lighting, total and primary energy demands, is 0%, 20%, 30%, 20% and 30% respectively.

3.5 Window-to-wall ratio on east and west façades (north 20%; south 60%)

In order to determine the most suitable window-to-wall ratios for both the east and west façade, the office building is simulated with a south-facing window-to-wall ratio of 60% and a north-facing window-to-wall ratio of 20%.

The following graphs show how the building's energy demands change with different east and west-facing window-to-wall ratios.

3.5.1 Heating energy demand

The building's heating energy demand decreases only slightly by increasing the east and west-facing window areas. This decrease is due to the increasing solar heat gains in winter. However, a greater window area also means greater heat loss in winter. Heat loss and solar heat gain almost cancel each other out. It cannot generally be stated that the size of the east and west-facing windows has a significant positive influence on the building's heating energy demand.

3.5.2 Cooling energy demand

The building's cooling energy demand rises by increasing the east and west-facing window area. This is due to the relatively high solar radiation in the east and west during summer, and thus the greater solar heat gains though larger windows.

3.5.3 Lighting energy demand

An increase in window area on the east and west façades is cause for a decrease in lighting energy demand. However, the effect is very slight and almost non-existent because the building already receives sufficient daylight through the north-facing and especially through the south–facing windows.

3.5.4 Total energy demand

By increasing the window-to-wall ratio on the east and west façades, the building's overall energy demand increases. This is due to the fact that the solar heat gains through the east and west-facing windows is higher in summer than in winter and the increase in cooling demand is greater than the decrease of heating demand. East and west-facing windows in buildings with south-facing windows are, therefore, a weak point regarding energy efficiency. If an office building has no south-facing windows, the east and west-facing windows will have a positive effect in reducing the total energy demand. Although these simulations actually suggest a window-to-wall ratio of 0 to 10% on the east and west side of the building to minimize the total energy demand, the window-to-wall ratio is nevertheless set at 10% due to the importance of daylight.

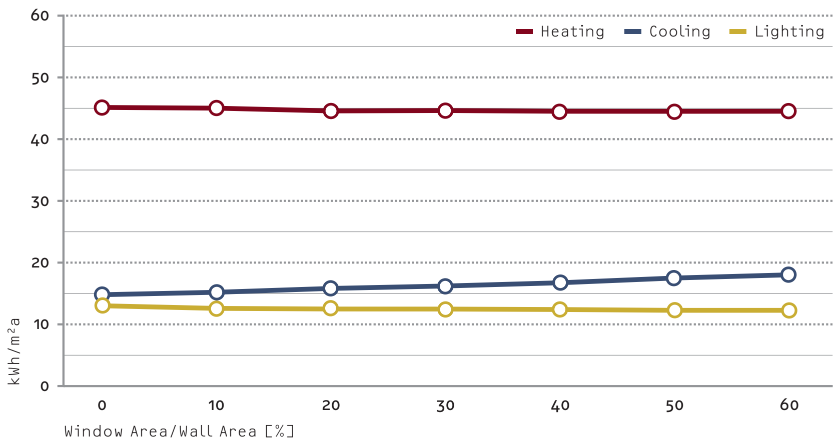


Fig. 32: Energy demands of office building with different east and west-facing window-to-wall ratios (kWh/m²a)

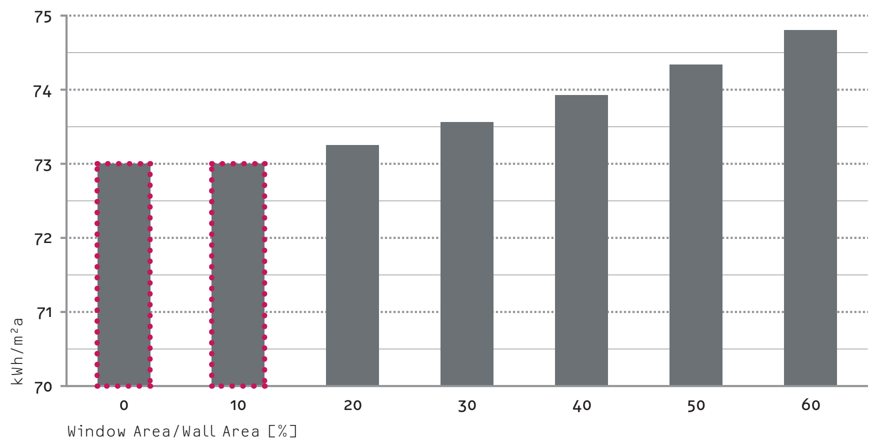
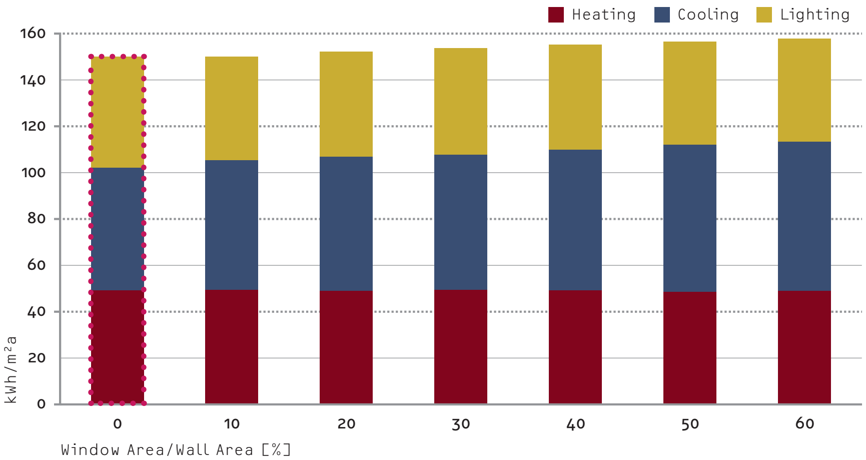


Fig. 33: Total energy demand of office building with different east and west-facing window-to-wall ratios (kWh/m²a)

3.5.5 Primary energy demand

The analysis of the primary energy demand offers no new insights than those already established by the total energy demand. It also shows a minimum demand with no windows on the east and west sides.



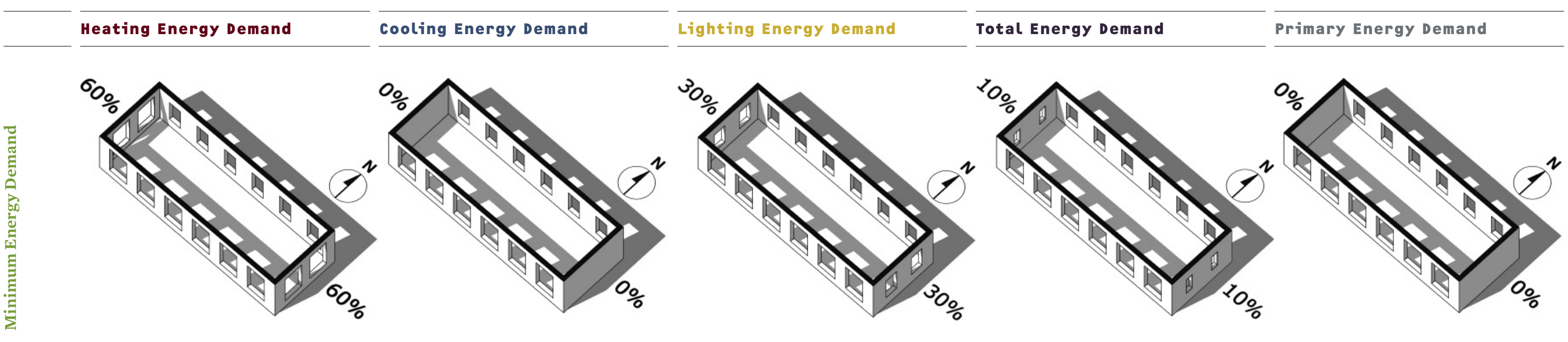


Fig. 34: Primary energy demand of office building with different east and west-facing window-to-wall ratios (kWh/m²a)
Tab. 7: Window-to-wall ratios on east and west façades for the minimum energy demands

Table 7 presents the window-to-wall ratios on the east and west façades for minimizing the heating, cooling, lighting, total and primary energy demands. The table shows that the building has its minimum heating, lighting and total energy demands at a window-to-wall ratio of 60%, 30% and 10% respectively. The best case for the cooling and primary energy demand is when the building has no windows on the east and west façades.

3.6 Conclusion

Various simulations have been performed to determine the ideal window-to-wall ratios for office buildings in regard of energy efficiency. Buildings with the same basic characteristics and the same climatic, structural and architectural conditions were simulated with varying window-to-wall ratios on all façades and were compared in terms of their heating, cooling, lighting, total and primary energy demands.

According to the results, the cardinal direction of a particular window area can significantly affect the energy demand. The window-to-wall ratio is, therefore, one of the most important architectural features to increase the building's energy efficiency. Optimizing a building's window area does not require any additional building materials or techniques, nor does it increase the investment costs. It does, however, decrease the life-cycle costs significantly by reducing the building's energy demand.

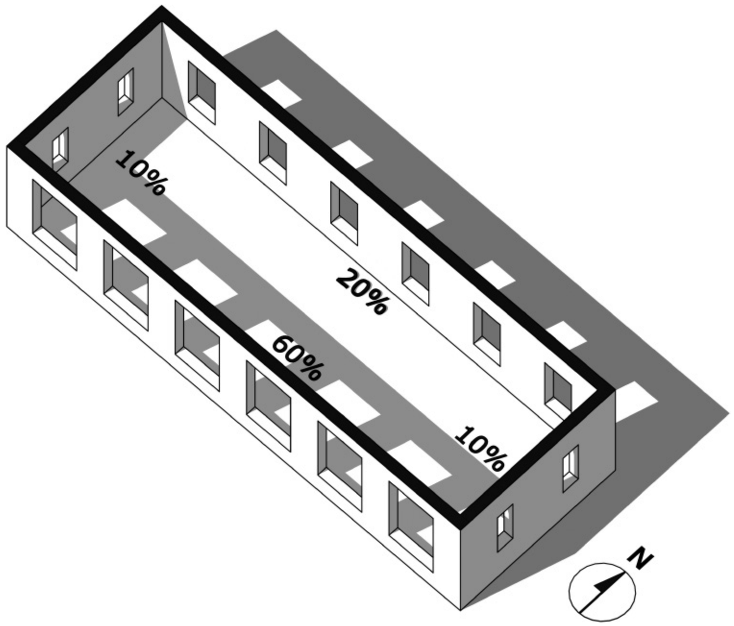


Fig. 35: Optimum window-to-wall ratio for minimizing the total energy demand

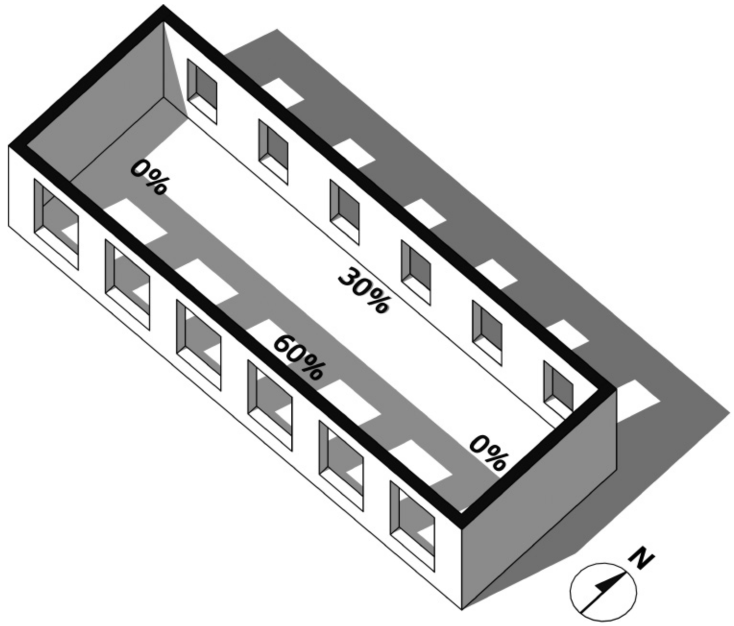


Fig. 36: Optimum window-to-wall ratio for minimizing the primary energy demand

The results show that:

- The energy demand of office buildings with different window areas varies significantly for buildings with and without shading devices.
- Buildings with the same window-to-wall ratio in all cardinal directions and without shading devices have their lowest total and primary energy demands at a window-to-wall ratio of 50% and 30% respectively.
- Buildings with the same window-to-wall ratio in all cardinal directions and with shading devices have their lowest total and primary energy demands at a window-to-wall ratio of 60%.
- South-facing windows have the greatest impact in reducing the total energy demand. Therefore, buildings require their largest window area with a 60% window-to-wall ratio on the south-facing façade.
- North-facing façades have their lowest total and primary energy demand with a window-to-wall ratio of 20 and 30% respectively.
- East and west-facing façades have their lowest total energy demand at a 0% to 10% window-to-wall ratio and their minimum primary energy demand at a 0% ratio.

Shading devices are very effective elements for reducing the cooling energy demand where internal and, in particular, external heat gains are the cause for uncomfortable conditions inside the building. This is especially the case in climates with warm summers. Shading devices affect a building's energy balance by preventing some of the solar radiation from entering the building through glazed areas and thus contributing towards higher temperatures inside the building.

External shading devices are much more effective than internal ones and have a smaller shading coefficient. This is due to the fact that the external devices obstruct the solar radiation before it enters the building and is converted into heat. Adjustable shading devices, if controlled accurately and in accordance with the heating, cooling and lighting requirements, are more efficient than fixed ones. On the other hand, these require greater financial and technical input, and are dependent on user behavior. Fixed shading devices reduce solar heat gain in winter too, which leads to a higher heating energy demand. Thus, each solution, fixed and adjustable, has its advantages and disadvantages and must be selected according to the specific needs of the opening.

4.1 Overhangs

In architecture, an overhang is usually a horizontal structural element protruding from the building above each window. The section in figure 37 shows how an overhang can help to prevent some of the sunlight from entering the building. It also illustrates how the overhang's depth influences the effect of the shading device.

Figure 38 shows the three main energy demands of an office building in relation to the overhang's depth. All windows, independent of the orientation, have the same overhang.

The diagram shows the following: By increasing the depth of the overhangs, the heating energy demand of the office building in the climate conditions of Hashtgerd increases, whereas the building's cooling energy demand decreases. These effects are due to the fact that the building's external heat gains are reduced in summer as well as in winter. The lighting energy demand increases slightly since larger overhangs lead to greater overshadowing.

Because the increase of the heating and lighting energy demand is greater than the drop in the cooling energy demand, large overhangs ultimately increase the building's total final energy demand. Therefore, in order to determine the minimum total energy demand, it is not recommended to use overhangs at windows in all four cardinal directions.

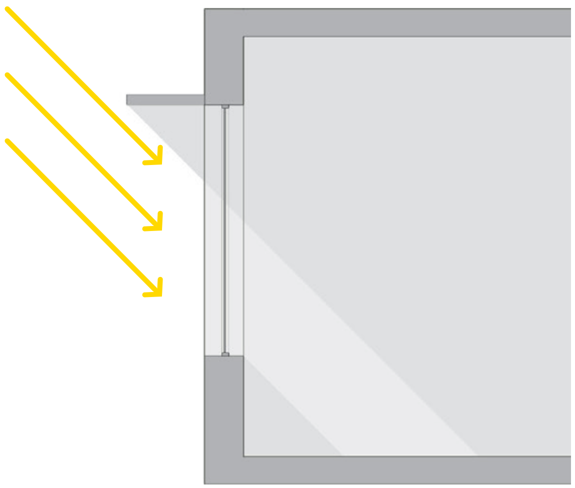


Fig. 37: Overhang

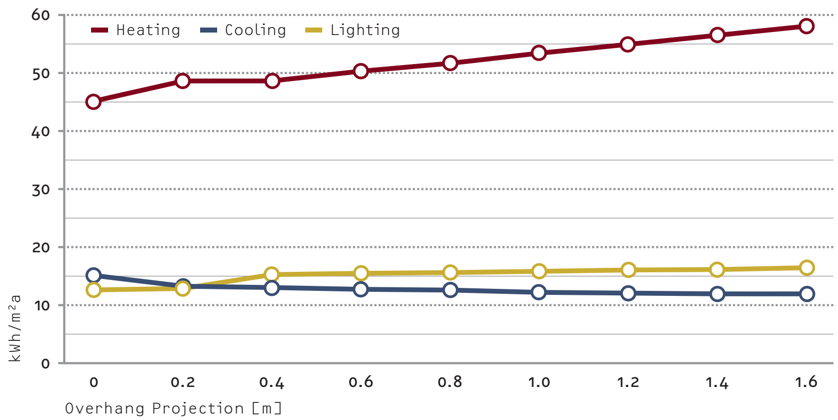
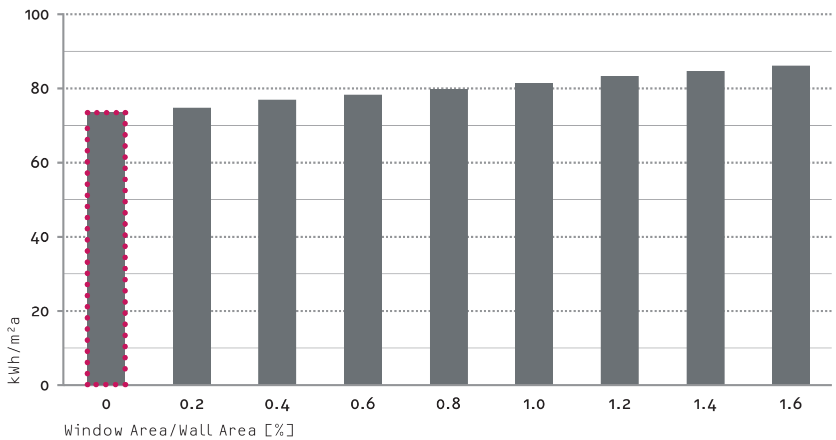


Fig. 38: Energy demands of office building with different overhang depths (kWh/m²a)

An office building with an overhang depth of 20 cm has a lower primary energy demand than a building without any overhangs. However, if the projection of the overhang is increased beyond 20 cm, the primary energy demand increases. Even though the building does not require any overhangs to meet the minimum total energy demand, the building reaches the minimum primary energy demand with overhangs projecting 20 cm. This is due to the fact that overhangs reduce the cooling energy demand (electricity), which has a higher primary energy factor.



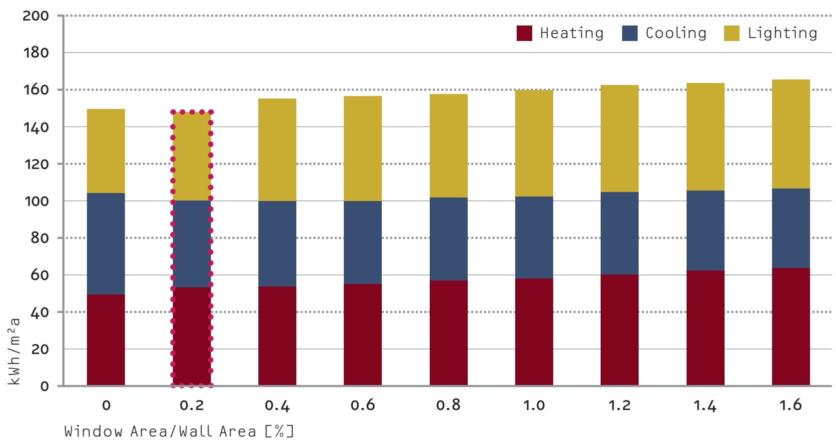


Fig. 39: Total energy demand of office building with different overhang depths (kWh/m²a) | Fig. 40: Primary energy demand of office building with different overhang depths (kWh/m²a)

4.2 External blinds

Since external adjustable shading devices affect a building's energy balance in different ways, for example the times when they are in use, the question of whether they should be controlled automatically to optimize the positive impact must be considered. Figure 42 shows that an external blind, placed in front of the window, does not have to be as static as an overhang. Its shading effect can be changed according to certain control strategies.

In order to study the effect of external blinds (and their control strategy) on a building's energy demands in the climate conditions of Hashtgerd, an office building without any shading devices and one with external blinds using different control strategies are simulated. Figure 42 compares the heating, cooling, lighting and total energy demands of the office building with and without external blinds. The results show clearly that the external blinds with different control strategies affect the heating, cooling, lighting and total energy demands of the office buildings quite significantly.

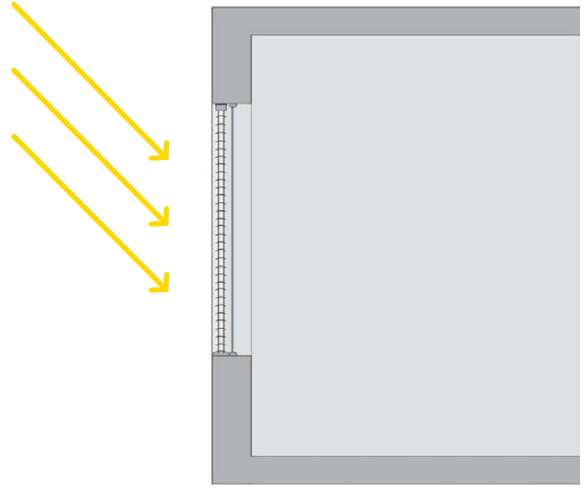


Fig. 41: External blind

4.2.1 Heating energy demand

The heating energy demand of an office building changes according to the control strategies of the external blinds. In the case of each strategy, the blinds are controlled according to the solar radiation, inside or outside air temperature, the need for daylight or solar radiation or within a set time period. An air temperature set point, a solar set point or a time schedule must be determined for each strategy according to which the blinds are closed or opened.

External blinds reduce the heating energy consumption of a building in comparison to not having any blinds, if they are controlled according to the following strategies:

- outside air temperature
- cooling and solar radiation during the day, and at night
- low outside air temperature at night
- low inside air temperature at night
- heating at night
- low outside air temperature at night and cooling during the day

4.2.2 Cooling energy demand

Most of the control strategies concerning external blinds decrease the cooling energy demand of office buildings. They only increase the cooling energy demand marginally, if they are controlled according to:

- outside air temperature
- low outside air temperature at night
- heating at night
- low inside air temperature at night

These mentioned strategies are therefore not recommended if the cooling energy demand is the main concern.

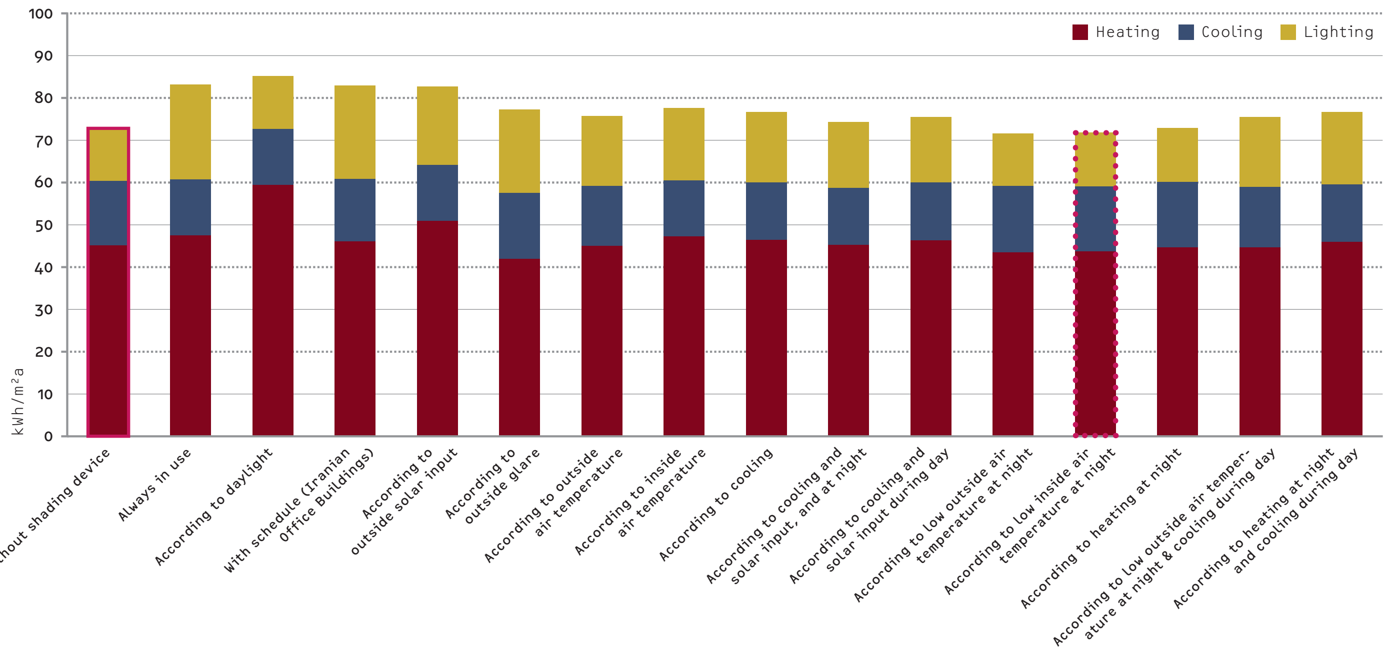


Fig. 42: Energy demand of office building with different external blind control strategies (kWh/m²a)

Five of the six above-mentioned strategies to reduce the heating energy demand are based on circumstances at night. This is due to the fact that, in winter nights, closed blinds reduce heat loss through long wave radiation from the warm inside surfaces to the cold outside atmosphere.

4.2.3 Lighting energy demand

All control strategies concerning external blinds increase the energy demand for lighting except the following four:

- daylight
- low outside air temperature at night
- heating at night
- low inside air temperature at night

4.2.4 Total energy demand

Only a few of the mentioned external blind control strategies reduce the total energy demand in the office building. These are:

- low outside air temperature at night
- heating at night
- low inside air temperature at night

If the external blinds are controlled according to these strategies, both the heating and lighting energy demands decrease; the cooling energy demand, on the other hand, increases slightly. This does not generally suit the initial task of a shading device, but it shows that shading devices, especially adjustable ones, can affect the heating and lighting energy demands too. It also illustrates that the use of blinds to minimize the total energy demand is actually a complex process. Their perfect operation depends on different factors including the time of year, time of day, outside air temperature, amount of solar radiation, solar altitude, solar azimuth, etc.

4.3 Conclusion

The effect of external blinds on the total energy demand of an office building is generally very slight. The high solar altitudes in Hashtgerd New Town, especially in summer, the short working hours in office buildings in Iran (and Hashtgerd New Town) and a large proportion of work being performed before noon are the main reasons for the little impact shading devices have on the energy demand of office buildings in this climate.

The simulations illustrating the effect of different-sized overhangs and external blinds on the energy demands also show that the use of overhangs as well as external blinds can even increase the office building's total energy demand in some cases. Nevertheless, the simulations are proof that an office building with external blinds requires less energy than an office building without any blinds, but that this is only the case if the blinds are controlled effectively. The use of automatic control mechanisms with menu options, such as "low outside air temperature at night", "heating at night" or "low inside air temperature at night", is essential to exploit the blinds' full potential. Adjustable external blinds require specialized materials and techniques. Wind and dust can pose problems for external blinds and are a challenge in terms of technical and planning aspects.

On the one hand, the application of adjustable external blinds increases the investment costs; on the other hand, the energy costs and therefore the life cycle costs of a building decrease. These results show that it is economically viable to apply sun shading devices in office buildings.

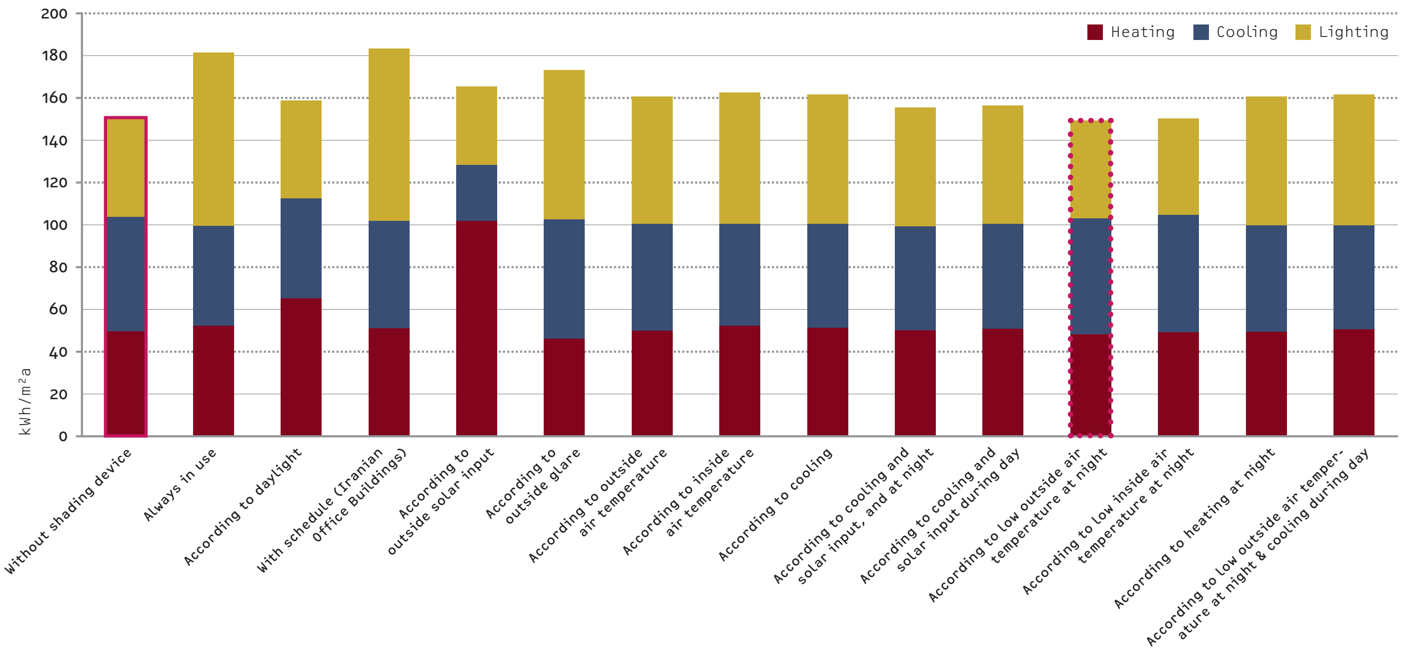


Fig. 43: Primary energy demand of office building with different external blinds control strategies (kWh/m²a)

4.2.5 Primary energy demand

The primary energy demand of an office building using different shading control strategies is similar to the performance of the total energy demand. As is the case for the total energy demand, only a few control strategies for external blinds have the potential to lower the primary energy demand. These are:

- low outside air temperature at night
- heating at night

III

New Generation Office Building

Design of an Energy and Cost-efficient Office Building

1 Goals and Strategies

Due to the high energy consumption of buildings in Iran, the main objective of the New Generation Office Building is to reduce the energy demand at the same time as improve the thermal comfort inside in comparison to similar office buildings in Iran. The secondary objective of the office building pilot project is cost efficiency.

To achieve cost efficiency, the aim is to save energy not predominantly through cost–intensive, but through cost-neutral methods, such as architectural energy efficiency, which does not increase the building costs. The architectural design is therefore the main tool for saving energy. Less emphasis is put on the construction and technology-related fields; nevertheless, these aspects are still considered in the energy efficiency approach. The New Generation Office Building is a demonstration pilot project for implementing the results of research and studies performed to achieve energy efficiency in office buildings.

Fig. 44: New Generation Office Building

2 Research Method

Prior to designing the New Generation Office Building, different studies, research and inquiries were carried through to produce a basis for the scientific and innovative design of this pilot project. These studies, especially those regarding energy efficiency, have accompanied the process of the building's architectural design. The following diagram illustrates the methodological approach, which was used for designing the New Generation Office Building.

At the beginning, the building site and users were analyzed. The results of the analyses and those of the theoretical inquiries regarding standards and regulations of office buildings provided the basis for the room schedule. Then, different building volumes were developed and examined regarding two aspects: 1) the urban design as well as the related urban neighborhoods, and 2) the micro-climate and the amount of solar radiation received by the outer surfaces of buildings.

Parallel to the mentioned studies and inquiries, basic research regarding energy efficiency in office buildings was performed. The results of the studies were used as a design guideline for developing the New Generation Office Building.

Once the design was complete, the pilot building was simulated, evaluated and its energy performance enhanced. Then, the materials of the thermal envelope were selected and optimized using thermal simulations. Finally, the building was economically evaluated.

3 Building Site

The New Generation Office building, as a green office, is planned for the Shahre Javan community in Hashtgerd New Town. One of the main representative locations within the Shahre Javan community for an office building was a site located in the south-west corner of this area. In the north and east, the site borders mixed-use areas with residential buildings as the main land use type.

It also has good infrastructural connections to other parts of the city, which is important for an office building that receives many clients. On the west and south sides, the site is surrounded by a 50 m-wide main road and a 45 m-wide main collector road, respectively. Furthermore, a 35 m-wide access road and a path/footway surround the site on the east and north side.

The location's topology is very pronounced, with a maximum difference in altitude of about 8 m. Since the plot of interest lies higher than the surrounding roads, it is the most suitable location for an office building within the 35 ha pilot area.

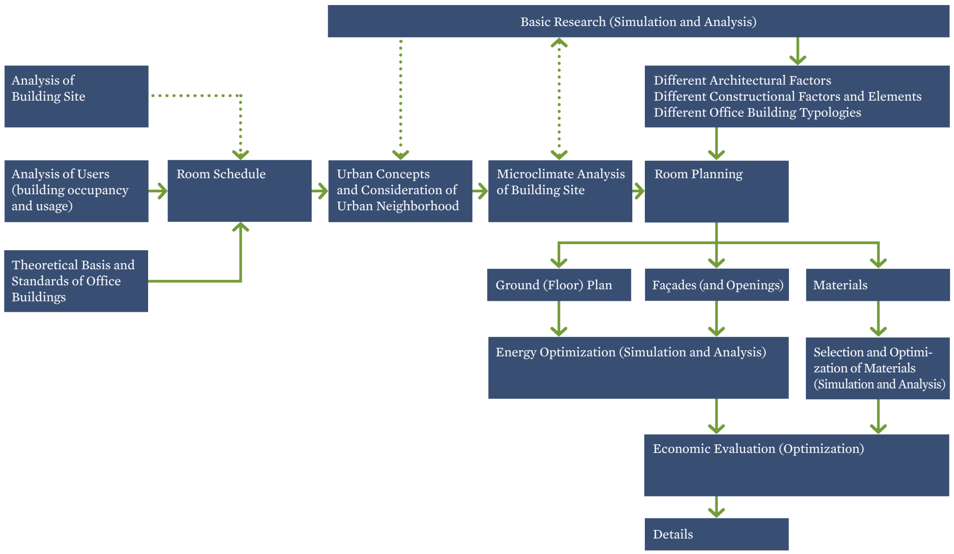


Fig. 45: Methodological approach for the New Generation Office Building (Research & Design)

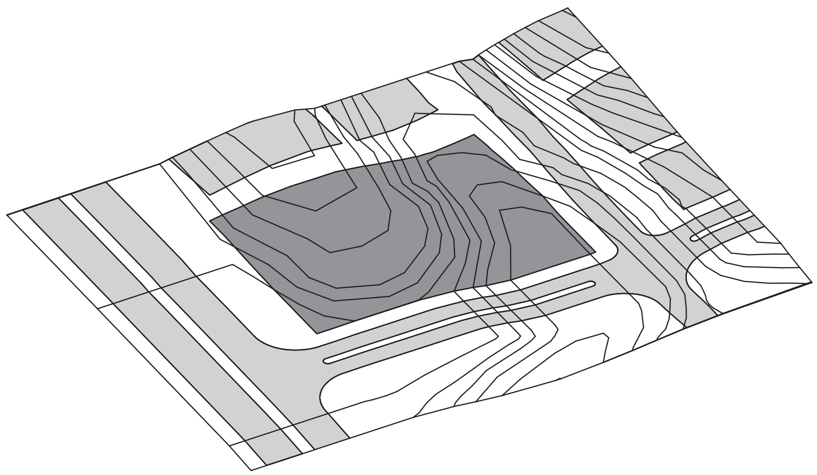


Fig. 46: Building site and site topography

3.1 Efficient use of building site

The designated building site is about 7,800 m²; the room schedule carried through for the New Generation Office Building suggests that the gross floor area of the building is around 3,000 m². According to the comprehensive plan of the Shahre Javan community, the maximum number of stories in this area is three. If the building is executed with three stories, the site occupancy index is only 0.13. This way, a great part of the site remains clear and can be used as open or green space. A site occupancy index of 0.13 is not very efficient from an economic point of view and does not match the surrounding urban concept with an occupancy index of about 0.7. Therefore and in order to increase the site occupancy index and achieve greater site efficiency, several alternatives are analyzed. The three alternatives are explained in the following.

The first alternative for increasing the site occupancy index is to divide the site along the east-west axis into two equally sized areas of 3,900 m². The southern part would then be used for the Hashtgerd branch of the "New Town Development Corporation" (NTDC) office building while the northern part could be a continuation of the surrounding urban usage, in this case a residential and mixed-use. Consequently, the New Generation Office Building would be planned within the southern part of the site. For this case, different building mass models and urban layouts have been analyzed for the office building and residential area.

The second alternative to achieve full use of the site is to build more office buildings than initially needed. These office buildings would allow the predetermined spatial requirements to be fulfilled and the excess space to be rented out as offices or even sold for commercial purposes. For this alternative, depending on the office area required within the Shahre Javan community as well as in Hashtgerd New Town, the final amount of gross floor area would have to be estimated for office buildings. Figure 49 shows different building mass models and urban layouts for the office building for the case that the whole site is used for the New Generation Office Building.

The third alternative is to develop a mixed-use area with a focus on office and related uses, such as architectural practices, consulting companies, banks, etc. The NTDC or other institutions could be the investor for renting or selling these buildings.

After analyzing the three alternatives and comparing their advantages and disadvantages, it seems that the best choice is to divide the site into two parts and introduce a commercial mixed-use area occupying the whole site. This is why a combination of the two alternatives is applied. Figure 50 shows different mass models for the whole commercial mixed-use area including the New Generation Office Building.

After dividing the whole site into two parts, the southern half is selected for the New Generation Office Building. The plot has an area of 3,900 m² and is located in the south-west corner of the Shahre Javan community. The northern part is not simply left for residential purposes, but is rather host to a commercial mixed-use area.

The exposed position of the New Generation Office Building in the south-west corner of the Shahre Javan community not only makes this office a very representative building, it also marks the southern "entrance" to the Shahre Javan community.

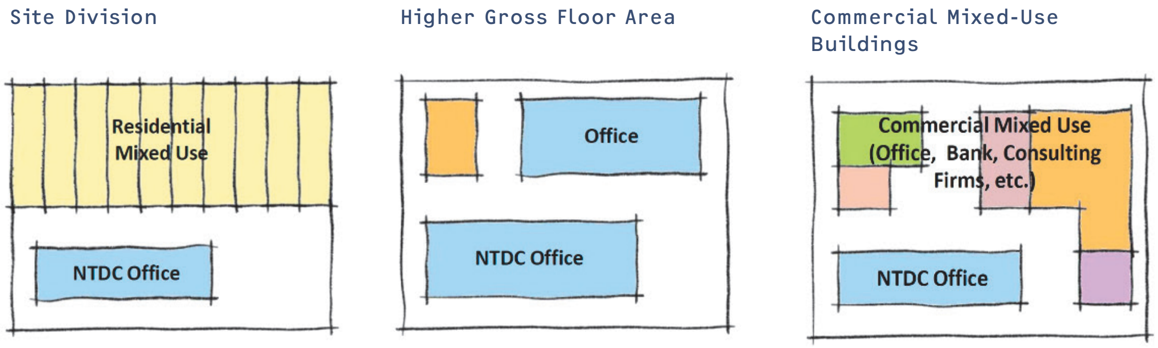
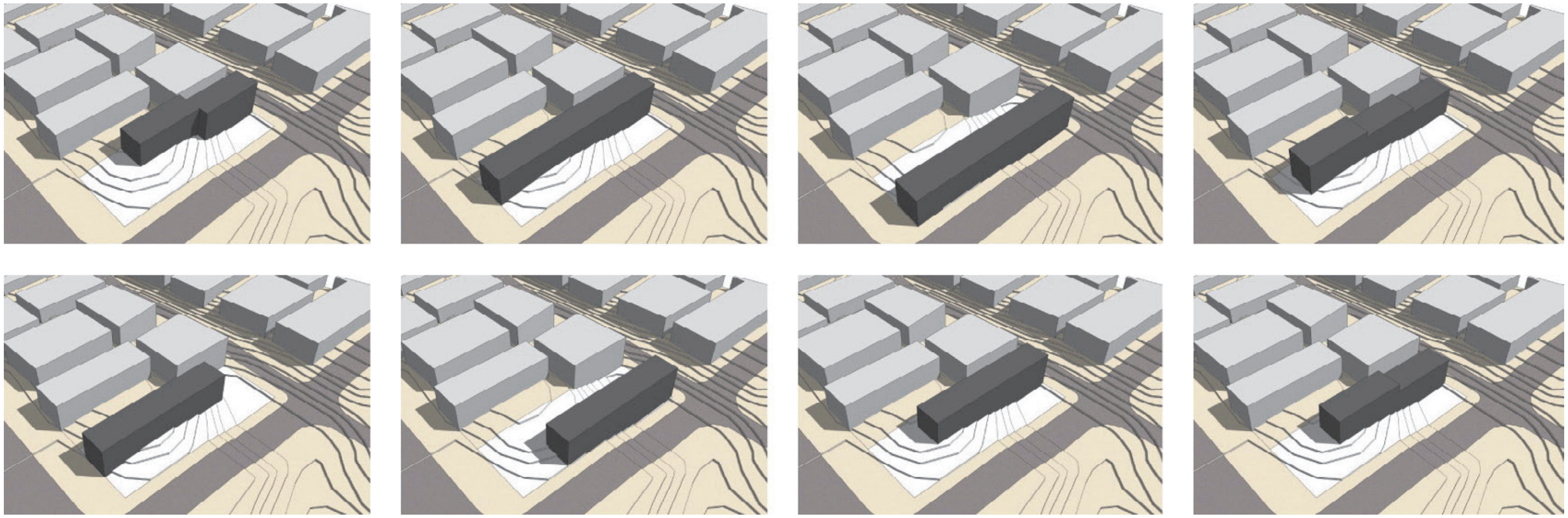


Fig. 47: Three alternatives for an area efficient occupancy



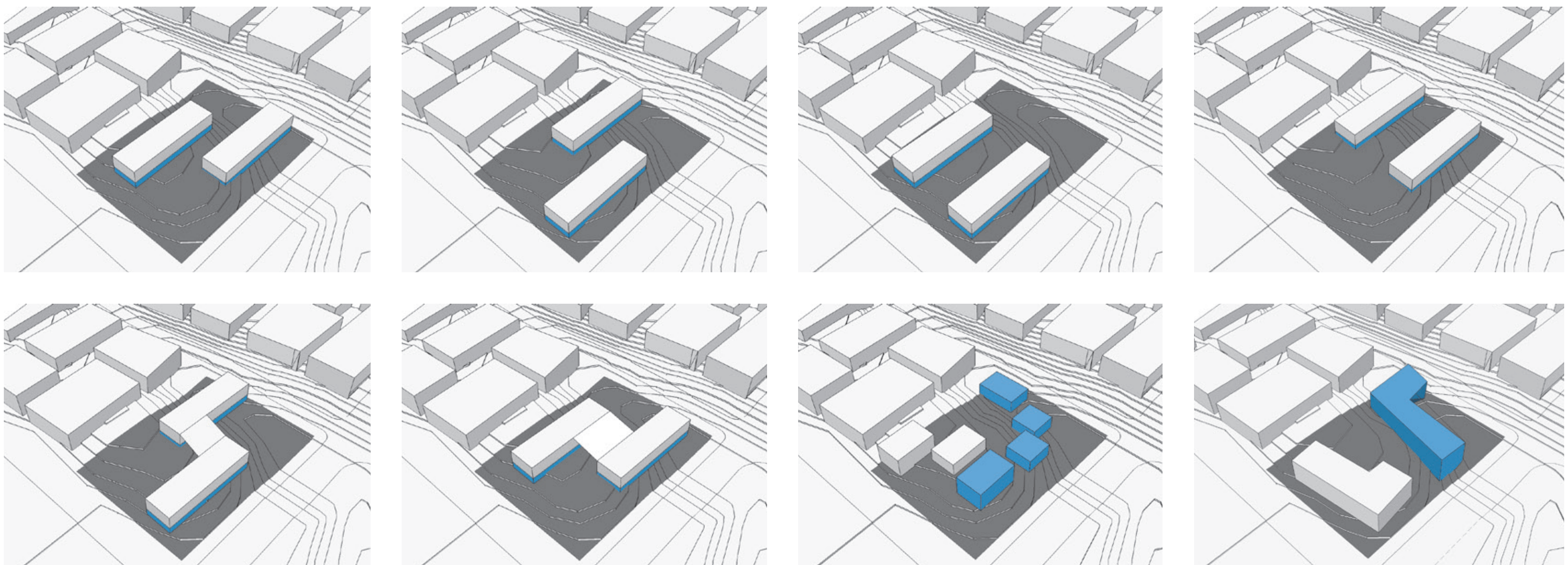
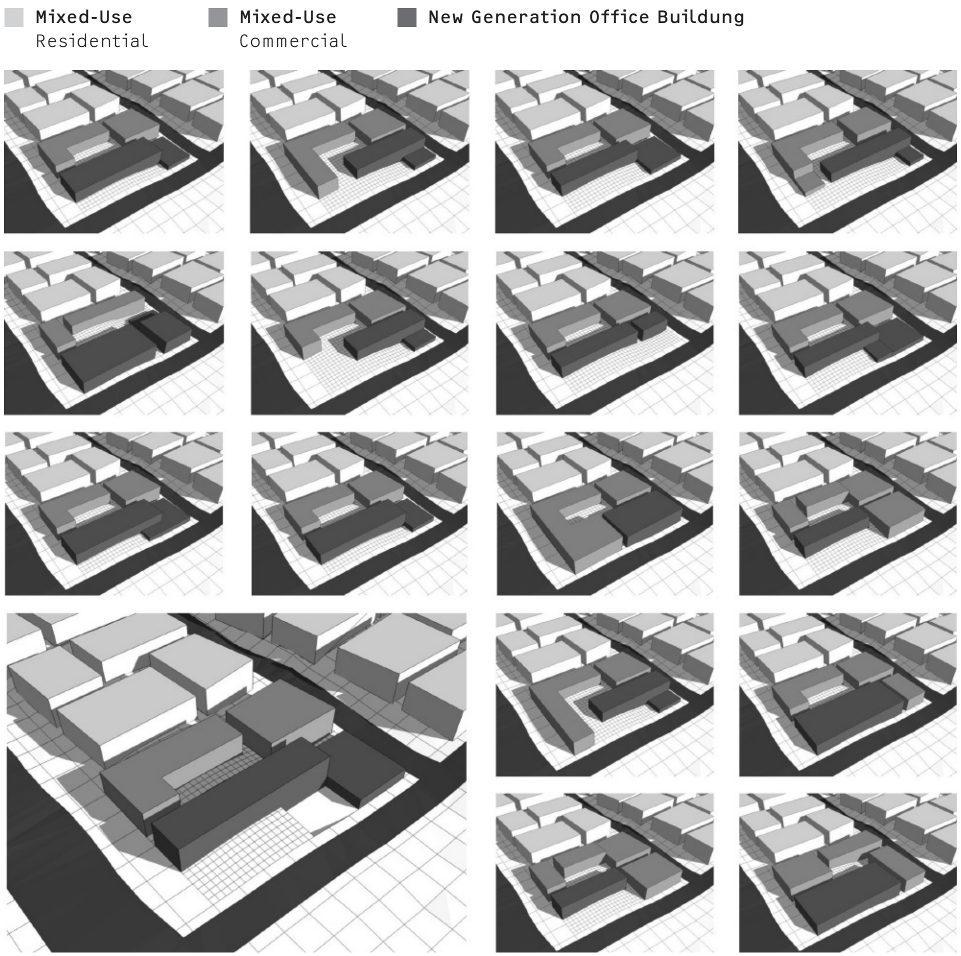
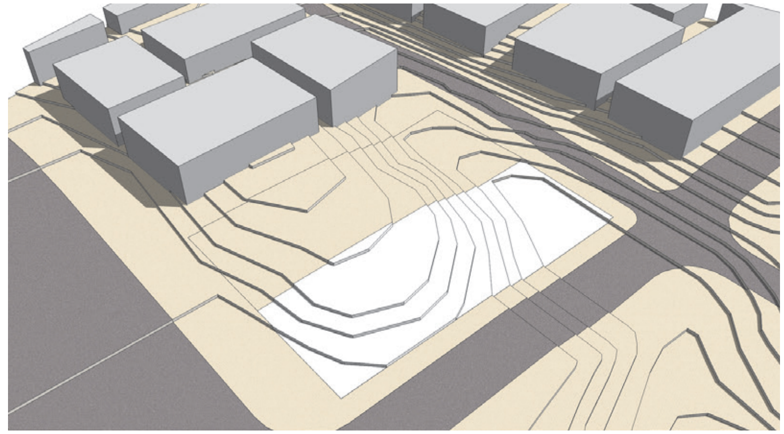


Fig. 48: Different mass models for the New Generation Office Building
Fig. 49: Different mass models for only the New Generation Office Building





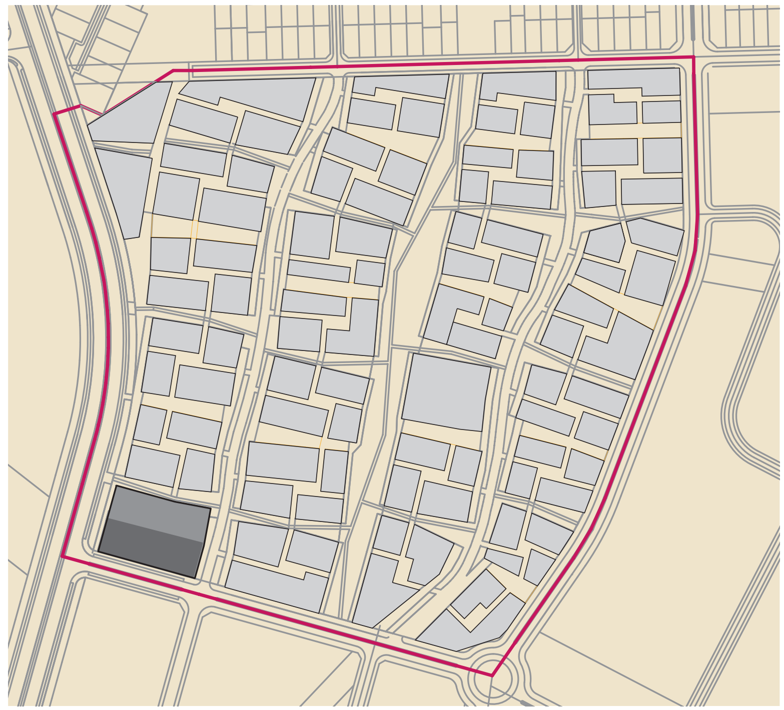
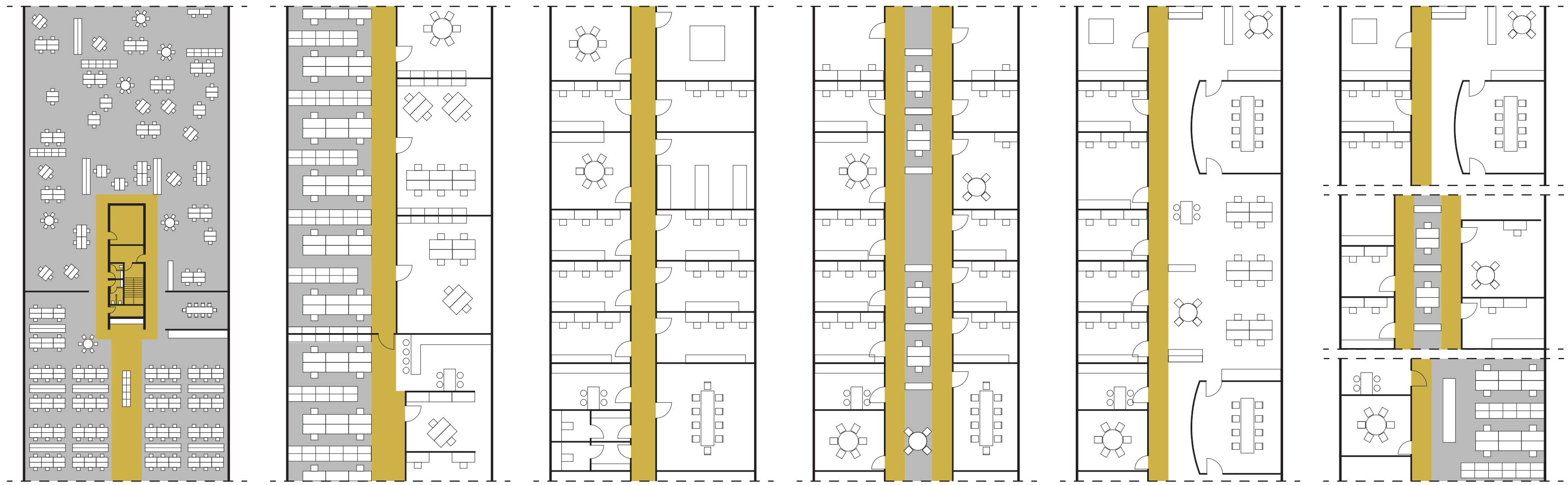


Fig. 50: Different mass models for the New Generation Office Building (commercial, mixed-used building complex)

Fig. 51–52: Site of the New Generation Office Building within the Shahre Javan community

For the design of this pilot project, various office typologies with their characteristics and spatial requirements were studied. Common office typologies include “open plan office”, “team office”, “individual office”, “combi-office”, “business-club” and “reversible office”. Among all typologies, two typologies, namely “team office” and “individual office”, are the most suitable ones for this building, especially from a social and work efficiency point of view. Therefore, a combination of the team and individual office type is thought to be most appropriate for this particular purpose.

Table 8 shows various office typologies with their spatial requirements and main characteristics.



	Open-Plan Office	Team Office	Individual Office	Combi Office	Business-Club	Reversible Office
Plan						
Advantages	•• Communication & team spirit •• Flexible arrangement of workplaces •• Flexible allocation of space	•• Communication & team spirit •• Short distances •• Workplaces of identical quality	•• Lighting and ventilation •• Privacy	•• Concentration and communication •• Individual control of lighting and ventilation •• High user acceptance	•• Spatial & organizational efficiency •• Individual control of lighting and ventilation	•• High Flexibility •• Sustainability
Disadvantages	•• Acoustic and visual disturbance •• Lack of privacy •• Artificial lighting and ventilation •• Expense	•• Acoustic disturbance •• Lack of privacy •• High percentage of façade area •• No individual climate control	•• Non-flexible monofunctional structure •• Lack of team spirit •• Corridor only for traffic purpose	•• Transparency of the individual office •• Waste of space in center zone	•• Lack of privacy •• Technical complexity •• Low user acceptance	•• No optional use of space •• Height between floors •• Expense

Tab. 8: Spatial characteristics of different typologies of office buildings (based on data from Eisele, 2005)

5 Physical (Spatial) Planning

Although the Hashtgerd branch of the "New Town Development Corporation" should be able to bear the costs and use the New Generation Office Building, the spatial arrangement and design of the building is based on high flexibility so that the building can also be used by other institutions and organizations. This is due to the fact that it is not quite clear whether the Hashtgerd branch of NTDC will be the owner of the building and then only stay in Hashtgerd, which is a new town, for a few years. The New Generation Office Building must therefore be a standard office building which can also be used by other corporations. The building is designed for 120 employees, but the room schedule and building design is actually performed to fulfill the spatial requirements of the NTDC Hashtgerd with 122 employees.

Concerning the space requirements of the pilot project, various regulations and standards regarding office space have been investigated. The results of this information inquiry have been used for calculating the floor area of different office spaces and ultimately the whole building.

The room schedule for the New Generation Office Building is developed according to the number of employees as well as the regulations regarding the spatial requirements of office buildings. It is based on both German and Iranian regulations and standards.

5.1 Room schedule according to German regulations

The first calculations of the space requirements for the New Generation Office Building were performed according to German standards and regulations. The principles of area dimensions are based on the "DIN 277" as well as the "Code of Measurement for Cost Planning" issued by the "European Council of Construction Economics". The German standard DIN 277 (Areas and volumes of buildings), which serves as a basis for the structured determination of building areas, is commonly used for planning and in the building industry in Germany. Other German regulations, which determine the space requirements for each employee, depending on the management hierarchy, are used for calculating the space requirements.

In order to examine the plausibility of the estimation concerning the gross floor area of the New Generation Office Building, three other calculations are carried through according to data from the "German Facility Management Association", the "Jones Lang LaSalle Real Estate Consulting Company" as well as the BKI (Baukosteninformationszentrum Deutscher Architektenkammern), the Construction Costs Information Center of the German Architectural Associations. This data is based on average values taken from several existing office buildings.

	Open-plan Office	Team Office	Individual Office	Combi Office	Business-Club	Reversible Office
Average Required Space per Employee (m²)	12–15	12–15	10–14	8–12	8–12	8–15
Room Length (m)	20–30	5–15	4.5–7.20	3.6–4.5	3.6–4.5/12	3.6–7.2
Room Width (single-user workstation) (m)	–	–	2.4–3	2.3–3	2.3–3	2.3–3
Room Width (double-user workstation) (m)	–	–	3.60–4.5	3.5–4.5	3.5–4.5	3.5–4.5
Building Depth (m)	20–40	12–24	12–13	14–17	from 14	14–15
Height Between Floors (m)	3.75–4.5	3.5–4.00	2.75–3	3.25–3.5	3.5–3.75	min. 3.75
Clearance Height (m)	min. 3	min. 3	min. 2.5	2.75–3	min. 3	min. 3
GFA/Workstation (single user) (m²)	–	–	33	23–26	–	23–33
GFA/Workstation (standard) (m²)	ca. 26.5	ca. 26–28	ca. 22.5	20–24	14–16	20–28
Number of Employees per Room	20–100	8–25	1/2–5	1/2–5	1.5–2	Concept dependent
NIA/office unit (m²)	400–1600	100–400	–	–	–	–
GLA/Workstation according (m²)	ca. 20.5	ca. 21	18–28	ca. 20	ca. 14	from approx. 20

GFA Gross Floor Area | **GLA** Gross Leasable Area | **NIA** Net Internal Area

Tab. 9: Spatial characteristics of different typologies of office buildings (based on data from Eisele, 2005)

Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area / Main Usable Floor Area

Office Areas according to DIN 277	Type of Use	Required Floor Area [m²]	Number of Persons	Number [unit]	Floor Area [m²]	Total Floor Area [m²]
Office Rooms	Single Cell Office – Executive Director	30.00	1		30.00	**779.25**
	Secretariat – Executive Director	12.00	1		12.00	
	Single Cell Office – Executive Board	24.00	4		96.00	
	Assistants – Executive Board	18.00	10		180.00	
	Combi Office – Specialized Employees	7.50	21		78.75	
	Combi Office – Employee	9.00	85		382.50	
Secondary Office Rooms	Copy Room/Zone	6.00		5	30.00	**207.70**
	Archive	6.00		5	30.00	
	Storage	6.00		5	30.00	
	Library	0.35	122	1	42.70	
	Reception Zone	15.00		5	75.00	
Tertiary Office Rooms	Conference Room	2.50	100	1	250.00	**1,223.00**
	Meeting Room (Executive Director)	2.20	30	1	66.00	
	Meeting Room (Executive Board)	2.20	20	3	132.00	
	Prayer Room	1.75	40	1	70.00	
	Canteen	1.80 + 0.40	60	1	132.00	
	Staff Room	1.20	30	1	36.00	
	Tea Kitchen	4.00		3	12.00	
	Car parking Space	12.50		42	525.00	
Ancillary Area to Main Function	Toilets Women	5.00	3	3	45.00	**144.00**
	Toilets Men	5.00	5	3	75.00	
	Toilets Invalids	3.30	1	3	9.90	
	Janitorial Room	6.00		1	6.00	
	Waste Room	8.00		1	8.00	
Ancillary Area for Services	Technical Space	10.00		3	30.00	**60.00**
	Server Room/Computing Center	30.00		1	30.00	
Circulation Area	Foyer	30.00		1	30.00	**654.00**
	Stairs – closed	16.00		3	48.00	
	Elevator	4.37	10		42.00	
	Corridor	100.00				
	Parking circulation	6.25				
Area of Partitions						**418.00**
Total Gross External Floor Area						**3,486.00**

Tab. 10: Room schedule of the New Generation Office Building according to the guidelines for the realisation of federal building

5.1.1 Guidelines for the Realization of Federal Building

In the room schedule performed according to the "Guidelines for the Realization of Federal Building" (RBBau), the main space requirement values are based on this regulation, unless there are no guidelines in the regulation regarding the space requirements. In this case, other references are used.

The main useable area, including offices (single cell office, secretariat, assistants' combi-office), secondary office space (copy room, archive, storage, reception zone) and tertiary office space (conference room, prayer room, canteen, staff room, tea kitchen and car parking space), is calculated according to the Guidelines for the Realization of Federal Building. The required floor area for the executive director is referred to as the standard for a head of department of a federal state authority with a 30 m² office area. According to these calculations, the total main usable area of this office building is 2,210 m².

Due to a lack of specific regulations regarding the ancillary areas for main functions (toilets, janitorial room, waste room), ancillary areas for services (technical space, utility room, server room), circulation areas (foyer, stairs, elevator, corridor, parking circulation) and areas for partition walls (10% of the gross internal floor area), these space requirements are calculated according to the results of information inquiries using different references.

5.1.2 Car parking

The estimations concerning the number of car parking spaces as well as the car parking circulation area are based on the building regulations of the German federal state North-Rhine Westphalia, called BauO NRW. The regulations determine that one car parking space is needed per 40 m² of useable office space. With an office area of approximately 1,684 m², the required number of car parking spaces would be 42.

Based on these regulations, 80% of the car parking spaces are for employees and 20% for clients; in this case, this means that 34 car parking spaces are reserved for employees and 8 for clients.

Area level	Office Areas according to DIN 277	GEFMA [%]	Total Floor Area [m²]
Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area / Main Usable Floor Area	Office Rooms Secondary Office Rooms Tertiary Office Rooms	62%	2,209
Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area	Ancillary Area to Main Function	4%	143
Gross External Floor Area / Gross Internal Floor Area	Ancillary Area for Services	3%	107
Gross External Floor Area / Gross Internal Floor Area	Circulation Area	20%	713
Gross External Floor Area	Area of Partitions	11%	392
Total Gross External Floor Area			3,563
Total without Car parking Area			2,775

Tab. 11: Room schedule of the New Generation Office Building according to GEFMA

Table 11 presents the summary of the room schedule, which is performed according to the Guidelines for the Realization of Federal Building. It specifies a gross external floor area of 2,698 m² and a car parking area of 788 m².

5.1.3 GEFMA

The second calculation to determine the average size of the different office areas is performed according to the German Facility Management Association (GEFMA). In this room schedule, similar to the first calculation, the main useable area is based on the Guidelines for the Realization of Federal Building. The other areas are extrapolated according to the GEFMA percentages. The total required floor area is 3,563 m² (2,775 m² without car parking).

5.1.4 Jones Lang LaSalle

The third calculation to determine the average size of the different office areas per workstation is performed according to the Jones Lang LaSalle Real Estate Consulting Company data of 2007.

Area level	Office Areas according to DIN 277	J. L. LaSalle [m²/WP]	Total Floor Area [m²]
Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area / Main Usable Floor Area	Office Rooms Secondary Office Rooms Tertiary Office Rooms	22.2	2,708
Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area	Ancillary Area to Main Function	1.4	171
Gross External Floor Area / Gross Internal Floor Area	Ancillary Area for Services	1.1	134
Gross External Floor Area / Gross Internal Floor Area	Circulation Area	7.2	878
Gross External Floor Area	Area of Partitions	3.9	476
Total Gross External Floor Area			4,368
Total without Car parking Area			3,580

Tab. 12: Room schedule of the New Generation Office Building according to Jones Lang LaSalle

Based on the total number of employees of 122, the office areas are extrapolated. The total required floor area is, thus, 4,368 m² (3,580 m² without car parking area).

5.1.5 BKI

The fourth calculation is based on data from the BKI (Baukosteninformationszentrum Deutscher Architektenkammern), the Construction Costs Information Centre of the German Architectural Associations. BKI determines the average area for a workplace.

The office areas are calculated based on the average area of a workplace in a high standard office building (42.21 m²/WP) and the percentage of the total gross floor area. The total required floor area is 5,150 m² (4,362 m² without car parking area).

Floor area level	Office Areas according to DIN 277	BKI 42.21 m²/WP [%]	Total Floor Area [m²]
Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area / Main Usable Floor Area	Office Rooms Secondary Office Rooms Tertiary Office Rooms	64.9%	3,342.1
Gross External Floor Area / Gross Internal Floor Area / Usable Floor Area	Ancillary Area to Main Function	5.4%	278
Gross External Floor Area / Gross Internal Floor Area	Ancillary Area for Services	3%	107
Gross External Floor Area / Gross Internal Floor Area	Circulation Area	18.1%	932
Gross External Floor Area	Area of Partitions	11.6%	597
	Total Gross External Floor Area		5,150
	Total without Car parking Area		4,362

Tab. 13: Room schedule of the New Generation Office Building according to BKI

5.2 Room schedule according to Iranian regulations

The room schedule estimation for the space requirements of the New Generation Office Building is also performed according to Iranian regulations. The regulations, which have been established by the "Iranian Planning and Budget Organization", recommend space requirements per employee depending on the hierarchical position.

Table 14 presents the room schedule of the New Generation Office Building performed according to Iranian regulations. Based on this room schedule, the New Generation Office Building has a gross external floor area of 2,227 m² and an additional 1,360 m² for car parking.

5.2.1 Car parking

According to the Iranian regulations regarding office building space requirements, one car parking unit is required for every 10 to 15 employees. Based on these guidelines, the New Generation Office Building only needs about 10 parking spaces. This does not seem plausible and the number of parking spaces is very small compared to the necessary car parking spaces calculated according to German regulations. For this reason, German regulations have been applied for the calculation of required car parking spaces, even in the room schedule which is based on Iranian regulations.

	Net Floor Area [%]	Horizontal Circulation Area [%]	Gross External Floor Area [m²]	Vertical Circulation Area [%]	Gross External Floor Area [m²]
Main Spaces (Group 1)	1,104.12	15–30	1,380.15		
Main Related Spaces (Group 2)	126.60	25	158.25		
Convenience Spaces (Group 3)	183.00	25	228.75		
Support Spaces (Group 4)	1,367.00	20	1,640.40		
Gross External Floor Area (without vertical circulation area)			3,407.55	3–5	**3,578**

Tab. 14: Room schedule of the New Generation Office Building according to Iranian Regulations

5.3 Comparison of room schedules

Table 15 and Figures 53–54 compare the space requirements of the New Generation Office Building according to the different regulations and recommendations.

Figure 54 illustrates that the space requirements of the New Generation Office Building, which are calculated according to average values of existing office buildings are higher than those calculated according to the various regulations. It also shows that the space requirements based on Iranian and German regulations are almost equal. Nevertheless, the principles of estimation as well as the space requirements for car parking are completely different.

The distribution of space for different sub-functional uses seems to be more detailed in the German regulations, e.g. in the Iranian regulations there are no requirements for the “areas of partition walls”. Based on the results of the comparison, a decision was made to predominately use the German regulations to establish the gross floor area of the office building.

<table>
<tr><th colspan="5">Office Areas according to DIN 277</th><th>German Standards Total Surface Area [m²]</th><th>GEFMA Total Surface Area [m²]</th><th>Jones Lang LaSalle Total Surface Area [m²]</th><th>KI Total Floor Area [m²]</th><th>Iranian Standards Total Surface Area [m²]</th></tr>
<tr><td rowspan="7">Gross External Floor Area</td><td rowspan="6">Gross Internal Floor Area</td><td rowspan="4">Usable Floor Area</td><td rowspan="3">Main Usable Floor Area</td><td>Office Rooms</td><td>779.25</td><td rowspan="3">2,209</td><td rowspan="3">2,708</td><td rowspan="4">3,342.1</td><td rowspan="3">2,575</td></tr>
<tr><td>Secondary Office Rooms</td><td>207.7</td></tr>
<tr><td>Tertiary Office Rooms</td><td>1,223</td></tr>
<tr><td>Ancillary Area to Main Function</td><td>144</td><td>143</td><td>171</td><td>176</td></tr>
<tr><td colspan="3">Ancillary Area for Services</td><td>60</td><td>107</td><td>134</td><td>278</td><td>39</td></tr>
<tr><td colspan="3">Circulation Area</td><td>654</td><td>713</td><td>878</td><td>932</td><td rowspan="2">797</td></tr>
<tr><td colspan="4">Area of Partitions</td><td>418</td><td>392</td><td>476</td><td>597</td></tr>
<tr><td colspan="5">Total Gross External Floor Area</td><td>3,486</td><td>3,563</td><td>4,368</td><td>5,150</td><td>3,587</td></tr>
<tr><td colspan="5">Total without Car parking Area</td><td>2,698</td><td>2,775</td><td>3,580</td><td>4,362</td><td></td></tr>
</table>

Tab. 15: Space distribution and sub-functional space requirements of the New Generation Office Building according to different regulations and recommendations

The New Generation Office Building has different spaces and rooms including the following:

- Management cell offices
- Regular cell offices
- Open-plan / team offices
- Meeting rooms
- Conference room/auditorium
- Reception area
- Cirulation space (foyer, corridor, stairs, elevator, etc.)
- IT equipment space (server room, computing center, copy room)
- Technical space
- Archive space
- Storage space
- Canteen
- Tea kitchens
- Staff room
- Library
- Janitorial room
- Waste room
- Prayer room
- Toilets (men, women, disabled)
- Car parking

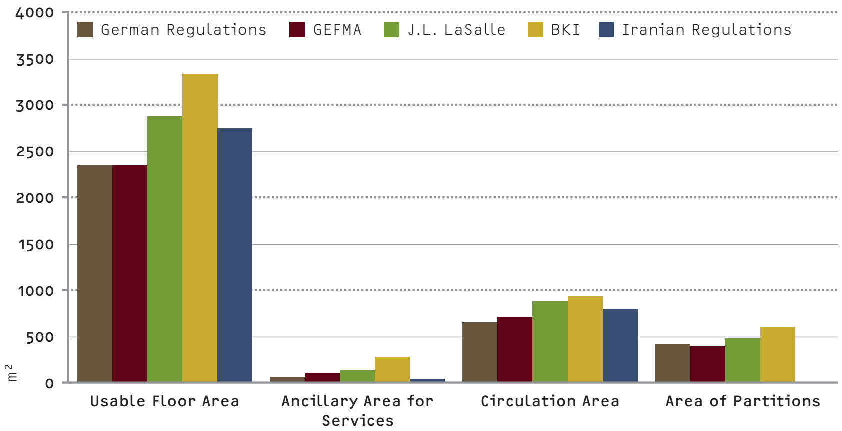


Fig. 53: Sub-functional Space requirements of the New Generation Office Building according to different regulations and recommendations

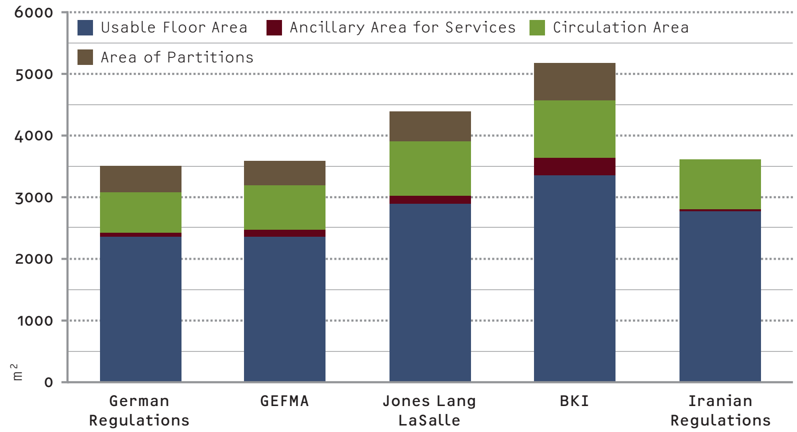


Fig. 54: Space requirements of the New Generation Office Building according to different regulations and recommendations

6 Building Materials

The New Generation Office Building has a reinforced concrete skeleton construction supported by shear walls for increased earthquake resistance. The foundations, columns, beams and slabs as well as the shear walls are made of in-situ reinforced concrete. The external and internal walls are constructed using light-weight materials, since these have a number of advantages over masonry walls commonly used in the Iranian construction sector. The light-weight materials reduce the building's overall weight and thus the costs and duration of the construction. The exterior walls are cladded with cement board on the exterior and gypsum board on the interior. The insulation material is located between the two layers. Straw, as an agricultural waste product, is used as the insulation material in the New Generation Office Building. Straw is a natural, non-toxic and renewable resource with low embodied energy. There is no energy demand for the production of straw, the CO_2 emissions for the production and costs are very low compared to traditional insulation materials. Furthermore, it is recyclable and thus a sustainable building material. It is available in all agriculture areas around cities, such as Hashtgerd New Town; the energy and financial resources required for the delivery to the building site are therefore very low. Straw as an insulation material is not only an environmentally-friendly material, it is also very cost-efficient. However, the thermal conductivity of straw depends on the density and is generally a little higher than traditional insulation materials. Compressed and sealed bales of straw are more combustion resistant than foam insulations due to the low concentration of oxygen in compressed bales.

7 Thermal Comfort

The internal air temperature of a building determines the amount of heating and cooling energy needed to create a comfortable indoor climate. Thermal comfort in office buildings is especially important since it affects job satisfaction significantly. Since the internal temperature is key for both the thermal comfort and the energy demand, some of the most important standards regarding thermal comfort, including ASHRAE Standard 55, ISO 7730, CIBSE (Guide A and B), have been reviewed and adapted in the light of the climatic conditions and social standards in Iran in order to define the summer and winter temperature limits in the New Generation Office Building. As a result, the operative temperature in all of the building's offices is kept above 21°C in winter and below 26°C in summer. The operative temperature in spaces with different uses and activities varies.

8 Optimization of Thermal Resistance

In addition to minimizing the building's energy demand through architectural design, a number of constructional (and technical) features have been investigated to increase the office building's energy efficiency and enhance its thermal performance without hugely increasing the costs. The research included an investigation into the energy savings achieved through insulating the external walls, the roof and the floors of the New Generation Office Building. The ideal U-values for all investigated elements of the thermal envelope were determined based on a calculation of the total energy demand, primary energy demand and CO_2 production of the building.

In order to study the effect of thermal insulation on the heating and cooling energy demand of the New Generation Office Building and to identify the optimal U-value of the thermal envelope, the building is simulated with four different groups of U-values for components of the thermal envelope. The first investigation considers average U-values of components in Iran's existing office buildings. The second investigation applies the U-values recommended by the Iranian national building regulations for office buildings in Hashtgerd New Town. As the U-values suggested by Code 19 of the Iranian National Building Regulations are very high, the U-values must be reduced. Therefore, in the third investigation, the value for each component within the thermal envelope is assumed to be half that of Code 19. In the fourth investigation, the U-values are even less than half of those in Code 19. The characteristics of the office building's thermal envelope are listed in Table 16.

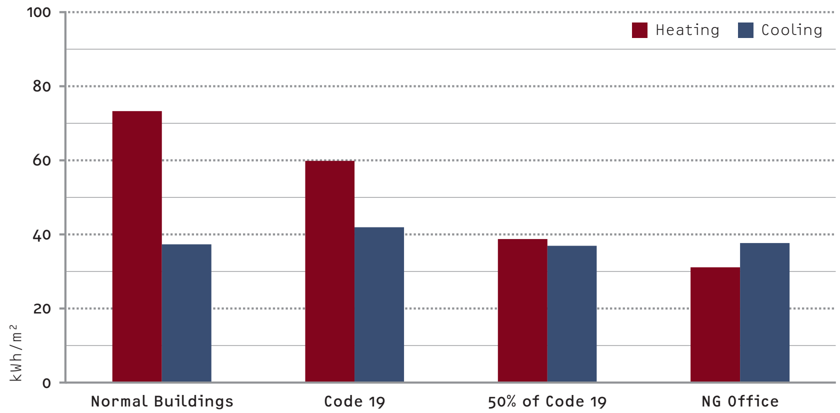
	U-Value			
	Normal Buildings	Code 19[1]	50% of Code 19	NG Office
External wall	1.8	1.61	0.81	0.25
External door		5.11	2.56	
Ground floor	2	1.4	0.70	0.43
Floor over exterior space	--	0.8	0.40	--
Roof	1.2	0.8	0.40	0.33
Window	5.778	4.96	2.48	2.48
Component adjoining unconditioned space		1.02	0.51	0.51

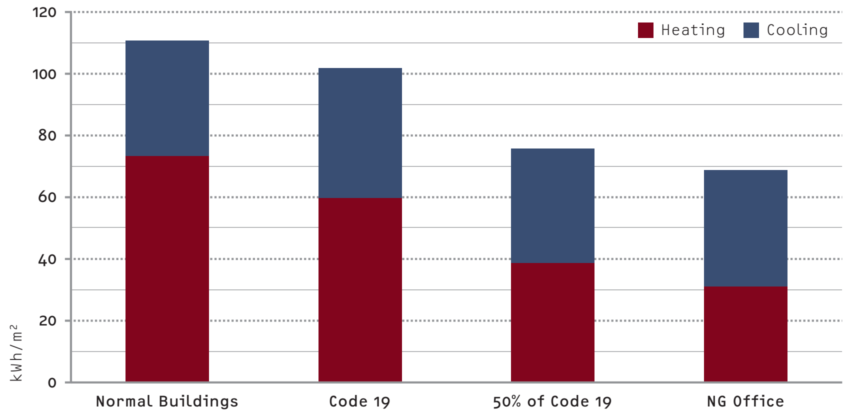
Tab. 16: Characteristics of the office building's thermal envelope

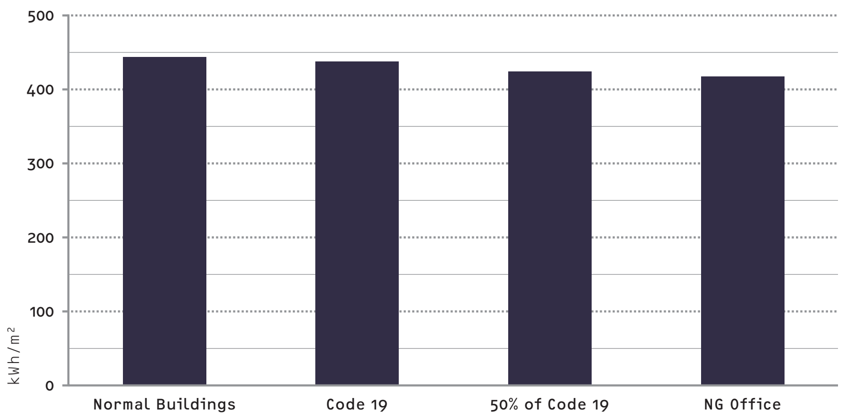
Figure 55 shows that the heating energy demand is reduced if the thermal resistance of the building envelope is increased. However, the U-value variations have different effects on the energy demand for cooling. The application of the Code 19 U-values, instead of those of existing buildings, leads to an increase of the cooling energy demand. An additional decrease of the U-values from Code 19 to half of Code 19 reduces the cooling energy demand; a further decrease to the standard of the

New Generation Office Building's thermal envelope increases the cooling energy demand again. Although the better thermal resistance of the envelope clearly decreases the heating energy demand, the effect on the cooling energy demand is completely different and the behavior is not linear. In terms of heating, a higher U-value leads to a decrease of heat loss, which in turn leads to a reduction of the heating energy demand. On the other hand, a lower heat loss does not always have a positive effect on the cooling energy demand. This is due to the fact that heat loss occurring in the cooling period sometimes has a positive effect and can actually lower the cooling energy demand. Heat loss only increases the cooling energy demand if the outdoor air temperature is higher than the internal temperature. But if the outdoor temperature is within a comfortable range or lower, heat loss through the thermal envelope decreases the cooling energy demand. A better thermal resistance of the New Generation Office Building's thermal envelope decreases the sum of heating and cooling energy demand significantly.

Although better U-values sometimes increase the cooling energy demand, as the following graphs shows, they lead to a decrease of the primary energy demand as well as the building's CO_2 emissions. The minimum U-values have therefore been selected for this building, which is now called NG Office thermal envelope.







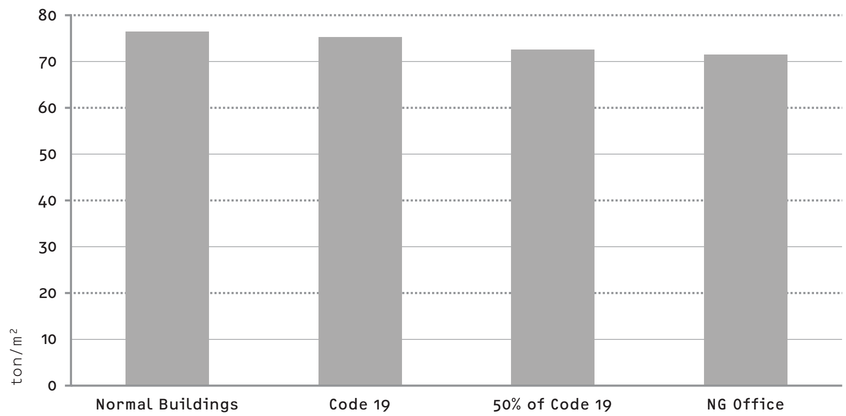
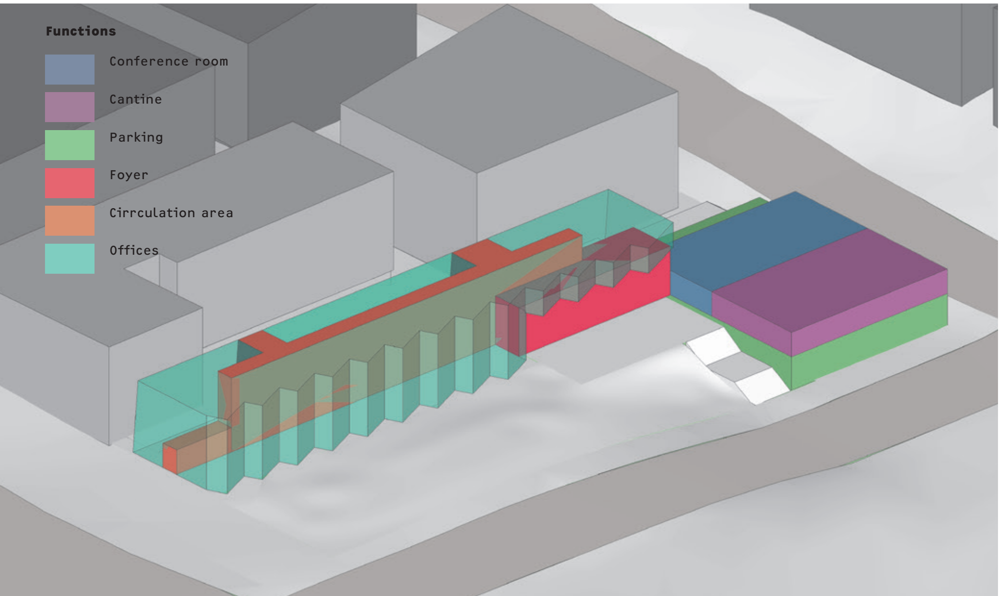


Fig. 55: Effect of thermal envelope U-values on the heating and cooling energy demands | Fig. 57: Effect of U-values on the primary energy demand for heating and cooling

Fig. 56: Effect of thermal envelope U-values on the sum of the heating and cooling energy demands
Fig. 58: Effect of U-values on the building's CO_2 emissions

[1] Performance approach.



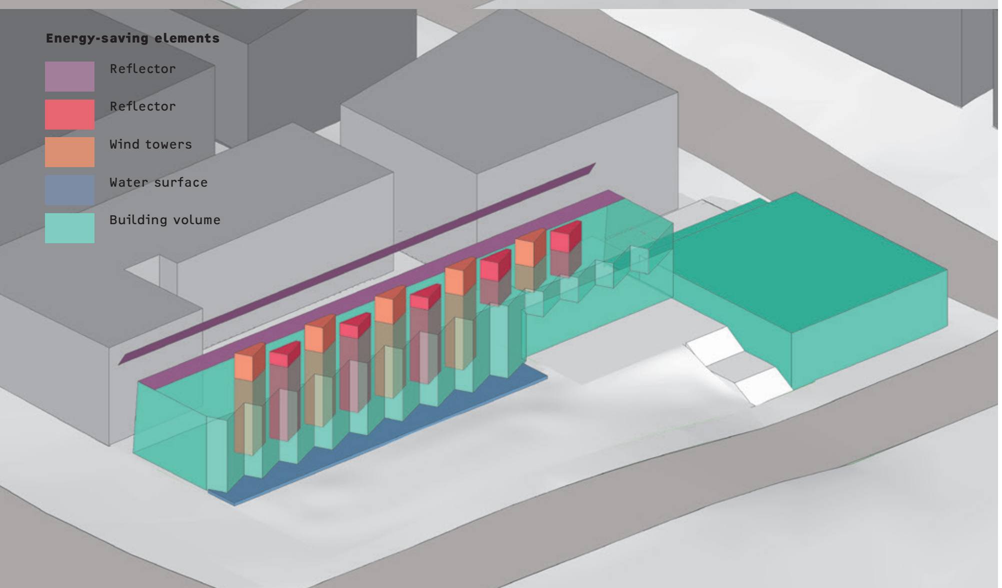


Fig. 59: Different usages (occupations) within the New Generation Office Building
Fig. 60: Energy saving elements of the New Generation Office Building

9 Architectural Design

Various alternatives were prepared for the architectural design of the New Generation Office Building. The drafts were evaluated and compared with each other to find the most suitable one. The New Generation Office Building was developed according to the results of simulations, analyses, theoretical inquiries and the room (spatial) schedule. The preliminary design was then evaluated from different viewpoints, including energy efficiency, and then finalized.

Figure 59 shows the building volumes with different usages (occupations). As the diagram presents, the building is formed by two main volumes: the eastern part, a thin and long volume with mainly offices, and the west volume, which includes semi-public space, such as car parking, a canteen and conference room. The car parking is located in the lowest part of the site and is in the basement compared to the other floors; nevertheless it is accessible from the street level in the east.

The conference room and the canteen on the ground floor of the east volume are designed as an extension of the office volume, so that there is the possibility for them to be used by the public as well as by other office buildings in the commercial mixed-use cluster.

Figure 60 presents the building volumes together with the energy-saving elements implemented in the New Generation Office Building, including solar reflectors, vertical roof windows, wind towers and water surfaces.

The results of studies regarding Architectural Energy Efficiency in office buildings, which are presented in Chapter II, are applied in the architectural design of the New Generation Office Building. These characteristics are as follows:

- "optimum building orientation" to achieve maximum solar heat gain in winter and minimum solar heat gain in summer
- "optimum window area in different orientations" to balance the heat gain in summer and winter as well as provide daylight and thus minimize the heating, cooling and lighting energy demands

Alongside these characteristics, the building includes some other concepts. The different concepts for the New Generation Office Building illustrate the innovative characteristic of the pilot project. They are designed to generate a sustainable building from an ecological, economic and socio-cultural point of view. These concepts include:

10.1 Optimal urban form

The natural as well as the artificial environment affect a building's energy balance. Together with the vegetation and water bodies, these natural and artificial features produce microclimatic conditions that not only influence the energy-related aspects, but also the comfort conditions of a building. Alongside the effects of the natural environment in a microclimate, buildings interact on behalf of the received solar radiation and both the wind direction and speed; with the solar radiation, however, being the most influential factor. Buildings in an urban complex can, on the one hand, overshadow each other at different times of the day and year; on the other hand, they can reflect solar radiation and thus generate greater incidence on different surfaces, which is one of the key factors characterizing a building's energy balance. Furthermore, the features which contribute towards the urban form of a single building (including orientation, elongation, height, shape etc.) are among the most effective architectural factors of an energy-efficient design.

In order to minimize the heating and cooling energy demands, the building envelope (especially the transparent parts) must generate maximum solar gain during the heating period and minimum solar gain during the cooling period. The amount of solar heat reaching the different parts (surfaces) of the building's thermal envelope at different times of the day and year depend on the orientation of each surface as well as the shading created by the surrounding natural and built environment.

The urban form of a neighborhood unit, a building cluster and an individual building affect the solar heat gain both in regard of the surfaces' orientation (orientation and form) as well as the urban form and composition of the neighborhood units, and influence the shading between buildings.

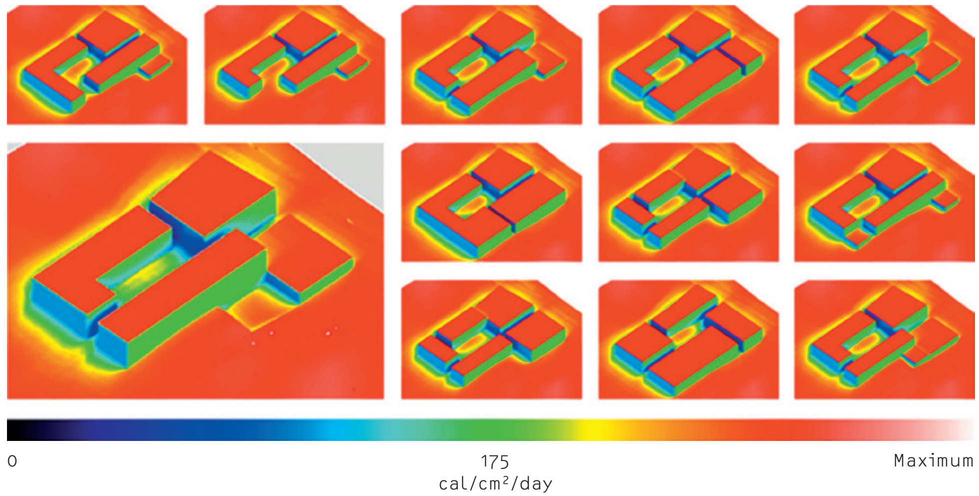


Fig. 61[1]: (top) Annual amount[2] of solar radiation incidence on the outer surfaces of the buildings in the cluster according to different urban forms[3]

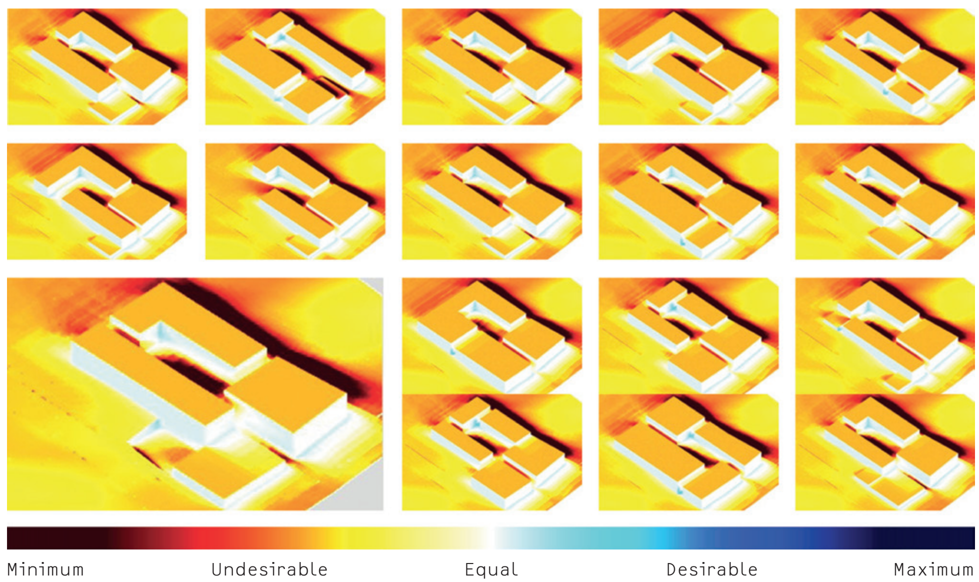


Fig. 62[4]: Surface characteristics concerning received solar radiation for different urban forms[5]

For the commercial mixed-use area on the south-west corner of the Shahre Javan community, different urban forms are evaluated for the building cluster (New Generation Office Building and other commercial buildings) regarding the intensity and duration of received solar radiation in different seasons.

In addition to the intensity of solar radiation incidence on the outer surfaces of the building throughout the whole year, the combined amount of solar radiation and air temperature (SolarVision) is calculated for different surfaces in the neighborhood unit. This factor presents the advantageous and disadvantageous characteristics of any surface from the viewpoint of received solar radiation at different times.

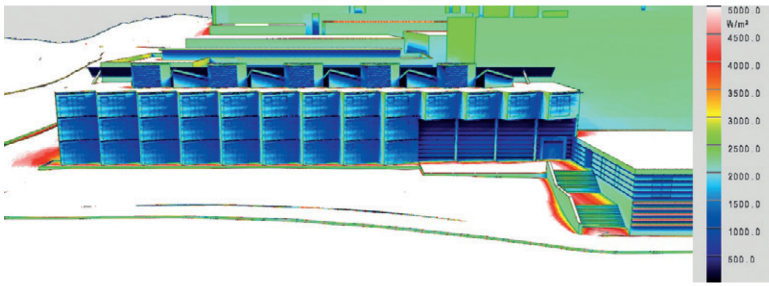
After selecting the best alternative, from the viewpoint of received solar radiation, the urban form of the building cluster is evaluated and improved so that the building envelope receives a high amount of solar radiation in winter and a minimum amount in summer.

Since the analysis of the optimal urban form is a planning and design tool for energy efficiency, it does not increase the investment costs of the building since no further material or technology is needed. By decreasing the energy costs, the building's life cycle costs are also reduced.

10.2 Optimal building form

It is not only necessary to optimize the urban form regarding the amount of solar radiation received by the building's surfaces in the heating and cooling periods, but also the building form to maximize the solar gains in the heating period and minimize them in the cooling period. Figures 63 and 64 present the incidence of solar radiation on the building surfaces in winter and summer respectively.

The form of the New Generation Office Building is optimized regarding the incidence of solar radiation in summer and winter. As the building site is oriented 15° west of south, which is a disadvantageous orientation for the building from an energy point of view, in particular for an office building, and due to the fact that the whole building could not be rotated to south because of urban limitations, only the south façade of the building is rotated 15° east of south. This has the effect that part of the south façade is overshadowed by itself, which decreases the solar heat gains in winter. For this reason, windows are also located on the west side of façade elements, which are not overshadowed. The result is that the windows have sufficient solar heat gain in winter and very little in summer. As the following figures show, the south façade with a small rotation to the east has resulted in a very positive orientation from the viewpoint of solar radiation incidence at different times. Furthermore, the windows are located in the most advantageous positions.



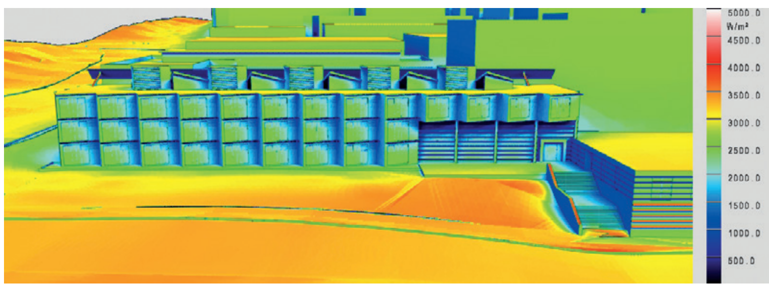


Fig. 63[6]: Incidence of solar radiation on the building surfaces in winter
Fig. 64[7]: Incidence of solar radiation on the building surfaces in summer

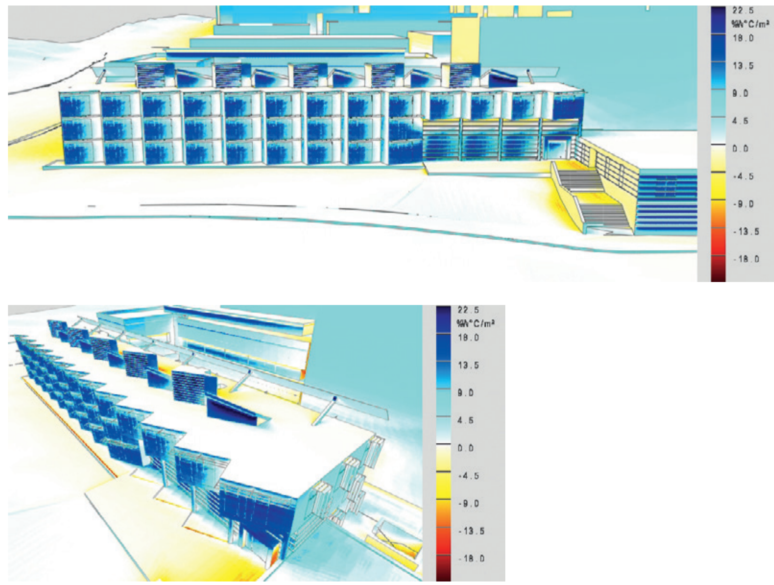
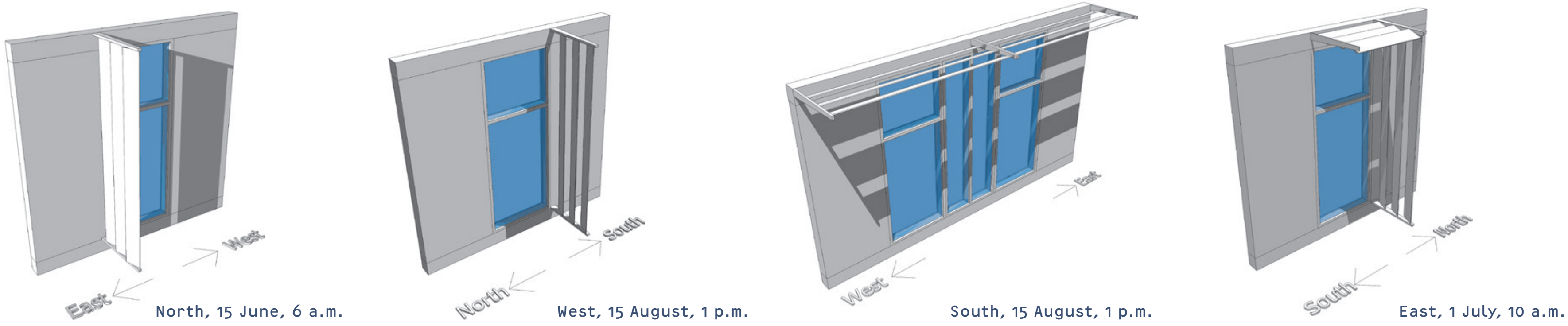


Fig. 65–66[8]: Advantageous and disadvantageous effect of solar radiation on the building surfaces

[1] Plotted by Samimi, 2011.
[2] 1 cal/cm² day = 4.25 kWh/m² a.
[3–5] Plotted by Samimi, 2011.
[6–8] Plotted by Samimi, 2013.



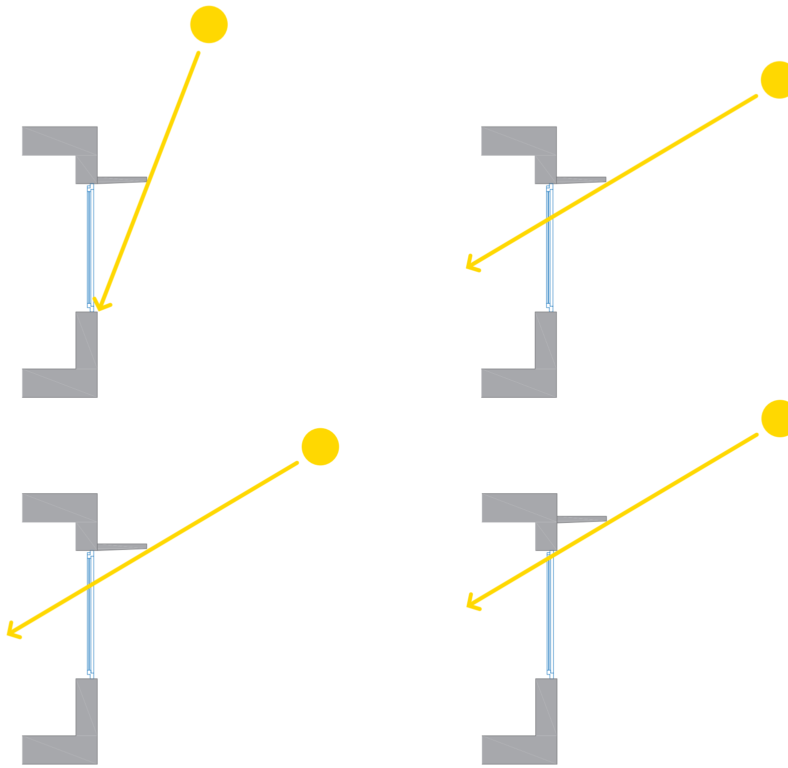


Fig. 67: Fixed shading devices for different cardinal directions
Fig. 68: Fixed shading devices on north façade

Fig. 69: Reduction of solar heat gain in summer by using overhangs
Fig. 70: Vertical offset of overhang to maximize heat gain in winter

10.3 Innovative fixed shading devices

Since cooling energy is required to remove internal and especially external heat gains, shading devices are very effective elements for reducing the cooling energy demand in climates with warm summers. Fixed shading devices are simple and inexpensive; furthermore, their cooling efficiency does not depend on the user's adjustment. However, they can reduce solar heat gain in winter, which in turn leads to a higher heating energy demand.

Especially overhangs, which are used at the south-facing windows of the New Generation Office Building, decrease the total energy demand most effectively if they create maximum shade at windows during cooling periods and minimum shade during heating periods. Based on the occupation time of office buildings, the shading devices are, depending on the cardinal direction, made of a selection or combination of horizontal and vertical elements.

10.4 Natural ventilation

Natural ventilation can help reduce the cooling energy demand while creating healthy room conditions. It is a process of supplying and removing air through an indoor space by making use of a natural pressure gradient. There are two types of natural ventilation in buildings: wind driven ventilation and stack ventilation. Natural ventilation can reduce the cooling energy demand of buildings effectively; however, it can also lead to increasing the heating energy demand if ventilation is performed at unsuitable times.

The reduction of the cooling energy demand by making use of natural ventilation is a very simple and economic way of energy efficiency.

This energy saving measure does not need any further resources. Natural ventilation can supply the fresh air required by the occupants, it can also help save investments cost if it helps to reduce the capacity of the building's HVAC system. Furthermore, natural ventilation contributes towards reducing expenses for maintenance, because it requires hardly any repair work. Moreover, it helps create healthy interior climate conditions and prevents moisture from entering and remaining in the building envelope. In the New Generation Office Building, natural ventilation is applied through wind towers, which combine natural ventilation and evaporative cooling.

Damp textile lamellae are installed at the top of the tower to increase the cooling effect of natural ventilation. The wind towers, therefore, reduce the cooling energy demand of the building.

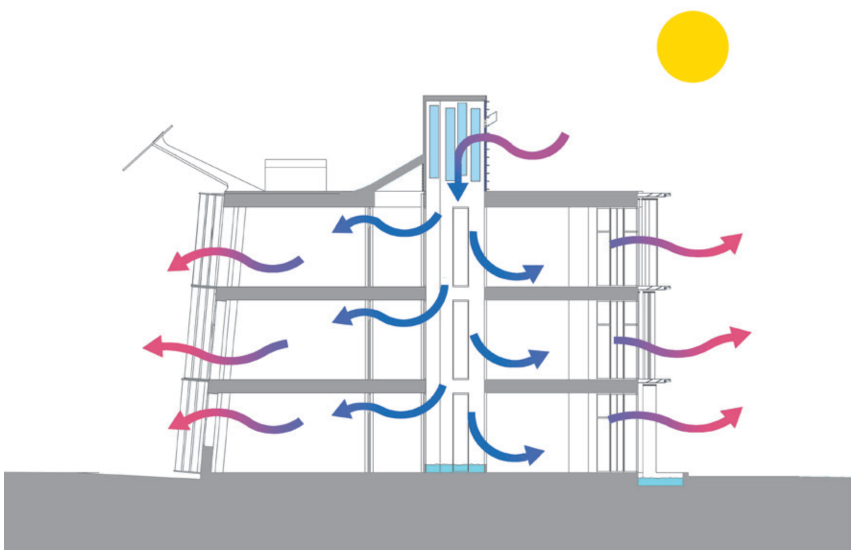


Fig. 71: Natural ventilation combined with evaporative cooling in summer

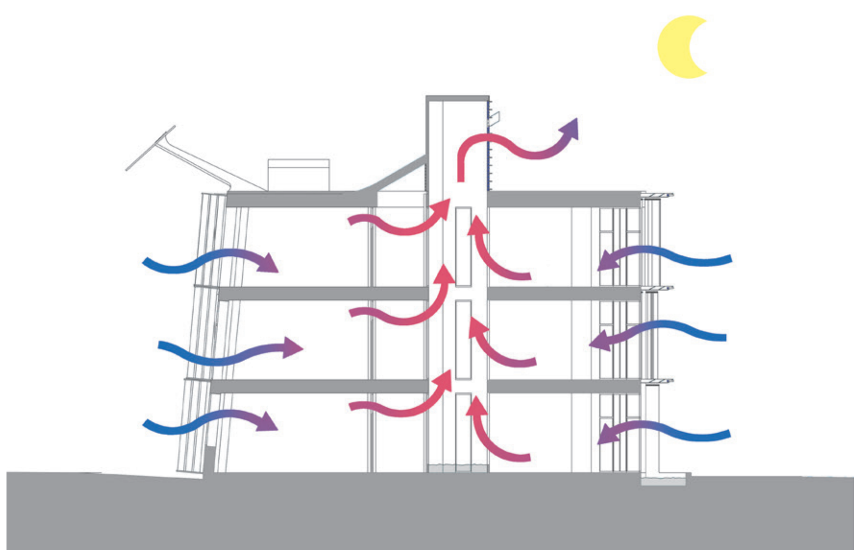


Fig. 72: Night cooling through windows and wind towers in summer nights

10.5 Hybrid solar heating through solar reflectors

The use of solar reflectors as a hybrid solar heating method to increase solar heat gain at north-facing windows can decrease the heating energy demand significantly.

The north-facing façade is the most crucial part of the building from an energy point of view. Here, the solar heat gain through transparent elements is very low during the heating period (the only heat gain is achieved through diffuse radiation), whereas heat loss is very high. If the high solar radiation, available in some continental climates, such as Hashtgerd New Town, were reflected onto the north façade, the north-facing rooms would also be able to receive some direct solar radiation. This solution would reduce the energy consumption for heating the building significantly.

The position and angle of the solar reflectors must be such that the panels reflect solar radiation onto the north façade only in winter and not in summer. Therefore, the position and angle of the reflectors must be determined accordingly.

Simulations are performed to study the effects of the reflectors on the amount of solar radiation reaching the north façade and to evaluate and optimize the position and angle of the reflectors. The results of the study for the New Generation Office Building show that a high amount of solar radiation is reflected onto the north façade. In order to increase the solar heat gain through the north-facing windows, the façade should not be vertical, but at a slight angle.

The use of reflectors to increase solar radiation on the north-facing surfaces reduces the heating energy demand and is an innovative way to create a more energy-efficient building.

The reflectors are low-tech and do not need any special technology; they are made of highly reflective metal panels, such as aluminum. The investment costs are therefore not very high and due to reduced energy expenses during the life cycle of the building, the investment for such reflectors is economically viable.

The water surfaces on the south side of the building can be used as solar reflectors to increase the solar heat gain in south-facing rooms in winter.

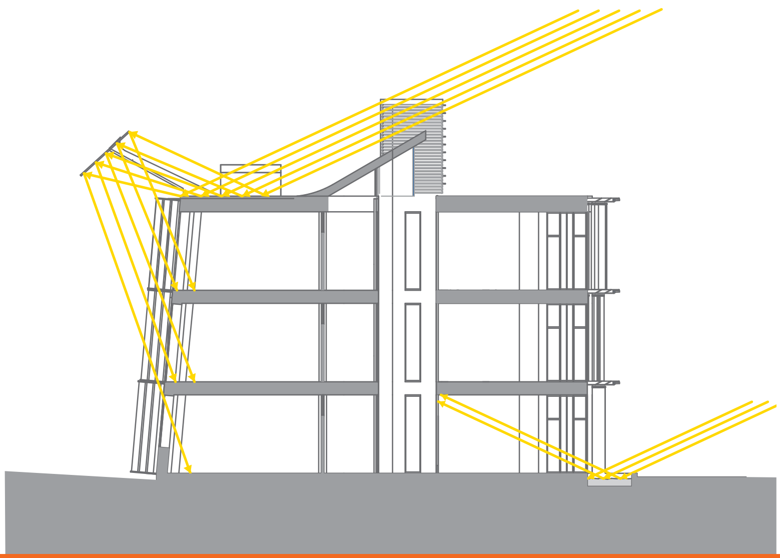


Fig. 73: Position and angle of solar reflectors in the New Generation Office Building

Fig. 74: View of the north façade with reflectors

10.6 Mechanical ventilation system with heat recovery

The total heating and cooling energy demand of office buildings increases if the air change rate through infiltration rises. The relationship between air change rate and total energy consumption is approximately linear.

Therefore, in order to reduce the energy consumption of buildings, the air change rate of buildings must be minimized. But in airtight buildings, the required amount of fresh air cannot be supplied through infiltration. Therefore, to ensure a suitable indoor air quality in airtight buildings, a mechanical ventilation system is required. Compared to a common construction system, the investment costs for a building with a low air change rate are higher. However, low air change rates are beneficial in that there is a high return on investments.

In buildings with a mechanical ventilation system, a specific amount of warm indoor air must be replaced by an equal amount of cold outdoor air to supply the required amount fresh air in winter. A significant amount of energy is consumed to increase the temperature of the cold outdoor air to the temperature of the indoor air. It is, however, possible to use the heat from the exhaust air for preheating the incoming air by applying an air-to-air heat exchanger.

By using a ventilation system with a heat exchanger in airtight buildings, the following objectives are achieved:

- Heat recovery from exhaust air which results in energy saving
- Supply of fresh air to the occupants in the occupied spaces
- Removal of air pollution from spaces with high pollution levels
- Control of the incoming air and elimination of dust, pollution, pollen, odours, etc. from entering the building

One of the characteristics of the New Generation Office Building is the installation of a mechanical ventilation system with a heat recovery system. The implementation of heat recovery in a mechanical ventilation system can help to maximize the building's energy efficiency. Air-to-air heat exchangers recapture a large proportion of the heat from the exhaust air. This process reduces the overall heat loss through the mechanical ventilation system to a minimum. Heat exchangers can achieve a heat recovery of up to 95%. Both, an air-to-air heat exchanger or a low-tech heat recovery system, are suitable heat recovery systems for office buildings.

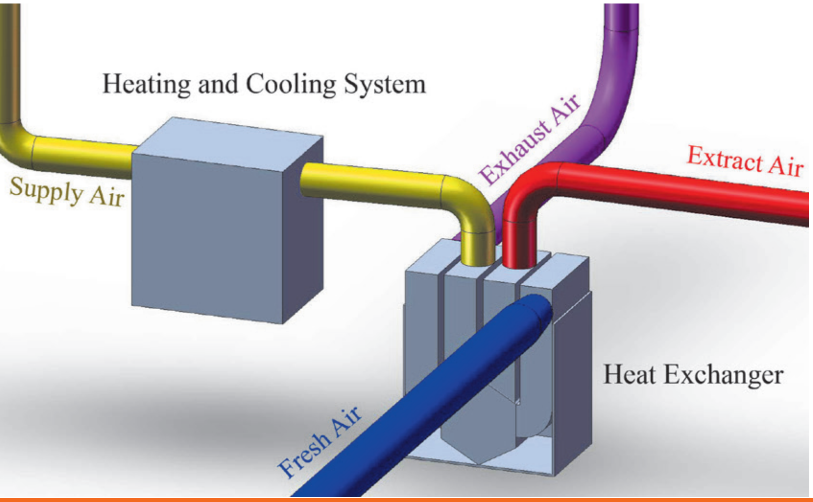


Fig. 75: The connection of fresh, supply, waste and exhaust air in a heat exchanger

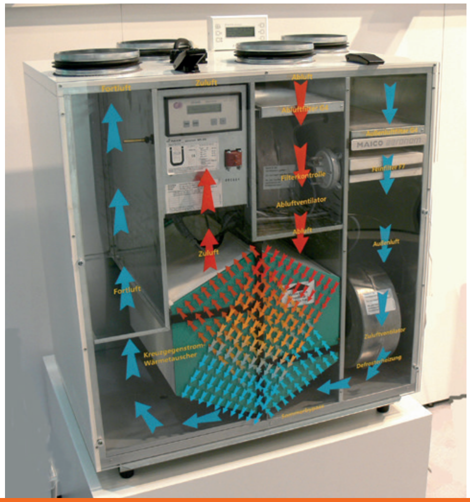


Fig. 76: Heat recovery concept in a heat exchanger

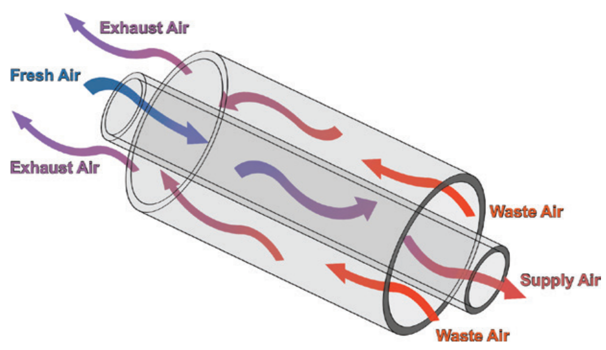


Fig. 77: The tube-in-tube construction as a low-cost method for heat recovery

10.7 Extensive green roof

The installation of a green roof can help minimize unfavorable thermal effects and maximize the durability of the roof. Energy savings, longer durability, improved micro-climate, high visual quality and a more pleasant environment for the employees are some of the advantages of green roofs. Some other possible environmental advantages of green roofs are as follows:

- reduction of the cooling energy consumption and cooling load of a building
- reduction and purification of storm-water runoff
- collection of rainwater provides effective watering
- reduction of smog
- improved air quality
- reduction of the urban heat island effect
- habitat creation and improvement of local biodiversity

The east block of the New Generation Office Building, which accommodates a canteen and conference room, has a green roof. It is mainly used to protect the top surface of the building from high-angle solar irradiation in summer. It decreases both the consumption of cooling energy and the cooling load of the building, which in turn reduces the necessary capacity of the cooling system. The planting marginally increases the thermal resistance of the roof, and thus reduces both the heating and the cooling energy demands. The planting increases the roof's durability and provides better insulation.

In summer time, the extensive green roof can be used as a recreational space. Green roofs are not typical for Iran. Therefore, the New Generation Office Building features a unique design element.

Compared to traditional construction systems, the investment costs for green roofs are higher. However, green roofs reduce the energy costs and the construction is more durable in regard of UV light protection. By adding a green space, the value of the building is increased. Additional studies must still be carried through regarding the economic viability and the payback time of green roofs. It is also crucial to determine which plants are most suitable for the climate conditions of Hashtgerd New Town.

Fig. 78: Green roof on the eastern part of the building

10.8 Semi-transparent architecture

The aim of transparent architecture is to improve communication, work motivation and user trust. Because the New Generation Office Building is a public building, one of the main architectural design criteria is to create a semi-transparent interior.

As a highly transparent office space cannot provide comfortable conditions for the employees, the office rooms are semi-transparent and can be seen indirectly from the corridor through the wind towers.

While traditional Iranian architecture is introverted, public buildings have to, by way of principle, be open to the public. Transparency has some important socio-cultural qualities. It can, for example in office buildings, increase the visibility of employees effectively, which, especially in the case of clients, helps to build client trust and increase work efficiency. Transparent architecture requires no specialized materials or techniques, and has therefore little impact on costs.

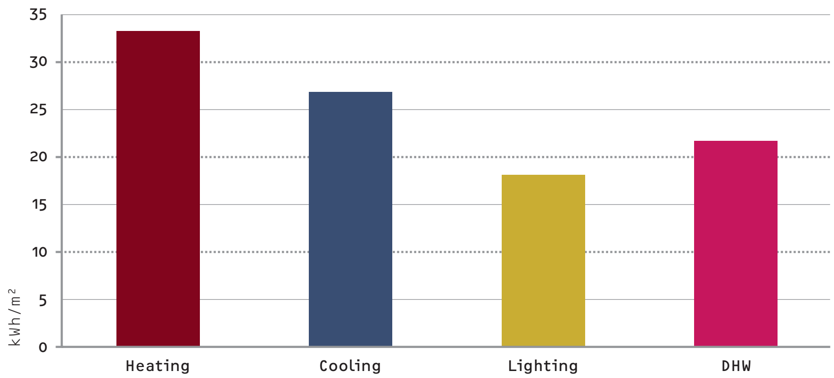
Fig. 79: Semi-transparent offices

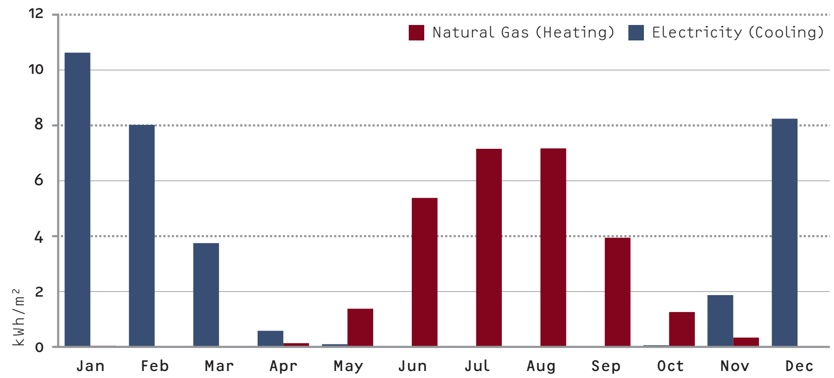
A transparent interior design can be implemented in two different ways: Either by using transparent interior walls or by creating semi-public spaces within the office building. Interior walls are partly built of transparent materials, such as glass, to increase the visibility between employees and visitors as well as improve the communication between employees.

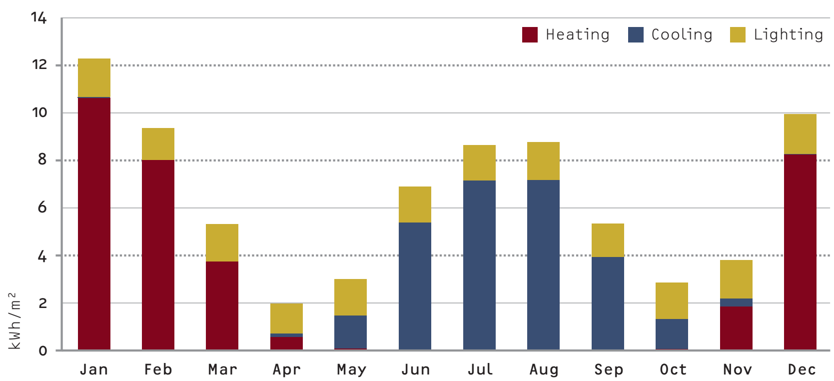
11 Energy Demands of the New Generation Office Building

The energy demands of the New Generation Office Building are calculated by performing simulations with DesignBuilder simulation software. Alongside factors such as climate conditions, architectural design and building materials, the heating, ventilation and air-conditioning systems (HVAC) also always have a significant impact on the energy demands of buildings. For simulation purposes, the HVAC system of the New Generation Office Building was conceived on the basis of the “General Energy Code[11]”. The simulations resulted in the following energy demands:

- heating: 33.26 kWh/m² a
- cooling: 26.85 kWh/m² a







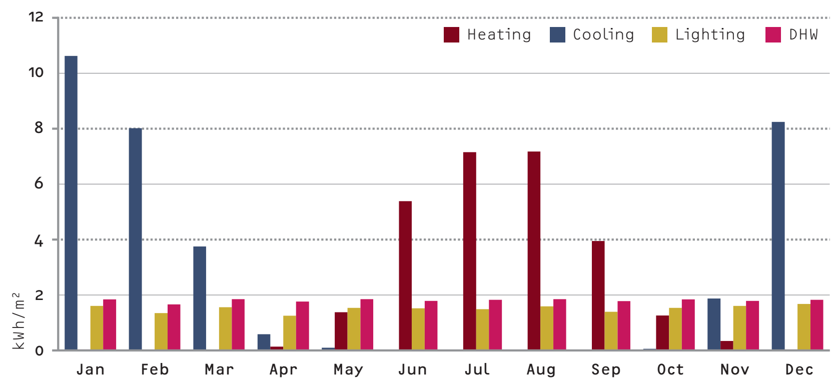


Fig. 80: Distribution of energy demands in the NG Office Building
Fig. 81: Monthly heating, cooling and lighting energy demands of the New Generation Office Building

Fig. 82: Monthly electricity and natural gas demands of the NG Office Building
Fig. 83: Monthly energy demands of the New Generation Office Building for heating, cooling, lighting and DHW

- lighting: 18.10 kWh/m² a
- domestic hot water: 22 kWh/m² a

As a result of applying architectural energy efficiency and energy saving concepts, the energy demand of the office building for heating, cooling, lighting and domestic hot water (DHW) is 99.87 kWh/m² a, which is about 80% less than that for a comparable office building in Iran. The low-cost, low-energy office building could easily be improved to meet the standards of a cost-efficient, zero-energy office building.

Figure 81 shows the monthly energy demands of the New Generation Office Building for heating, cooling and lighting. According to this graph, the building requires cooling from May to October and very little cooling in November. The heating system operates from November to April. Only little heating is required in April.

Figure 82 shows that the electricity consumption of the building for cooling and lighting is much higher than that of natural gas.

According to figure 83, heating and cooling have the highest energy demands out of all energy consumptions in the office building.

The building’s monthly primary energy demand is much higher in summer than in winter. That is because cooling is required in summer, which uses electricity and has a much higher primary energy factor than natural gas.

The sum of the building’s heating and cooling energy demand is 60.11 kWh/m²a, which is much less than the average energy demand of a conventional building in Iran. Based on Iran’s estimated primary energy factors, the primary energy demand of this building is 133.26 kWh/m²a for heating and cooling.

The New Generation Office Building is not only energy-efficient from a thermal point of view but is also efficient in terms of daylight by minimizing the energy demand for artificial lighting. The following

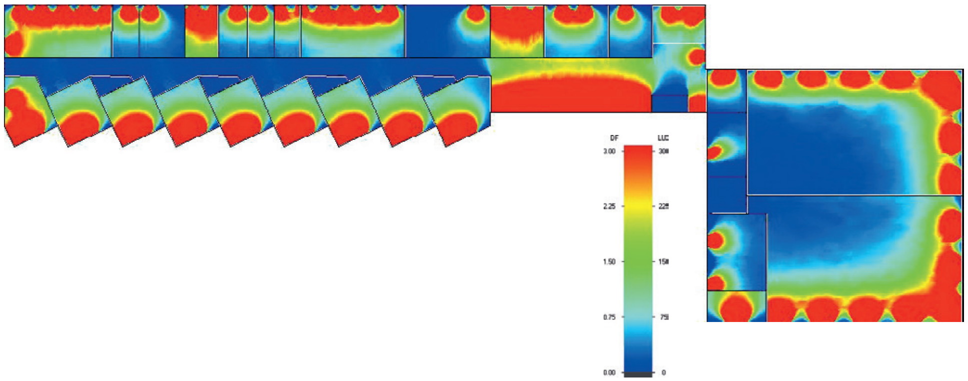


Fig. 84: Illuminance levels and daylight factors on the third floor of the NG Office Building

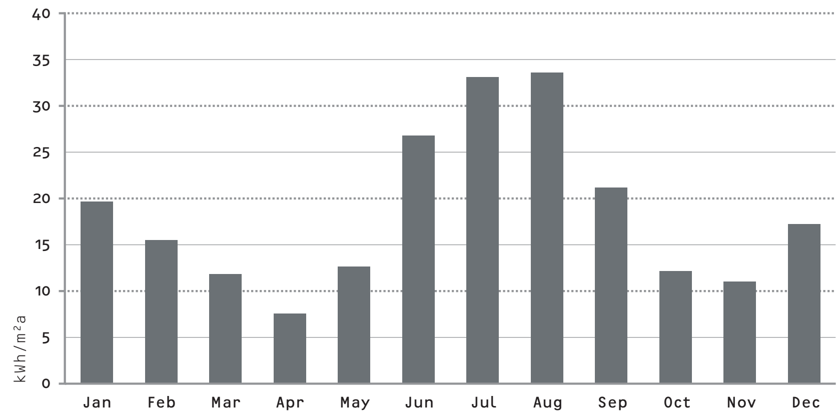


Fig. 87: Monthly primary energy demand of the New Generation Office Building

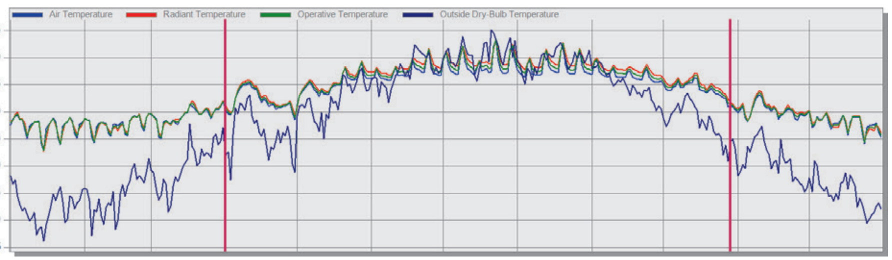


Fig. 85: Daily external air temperature and internal temperature in the NG Office Building

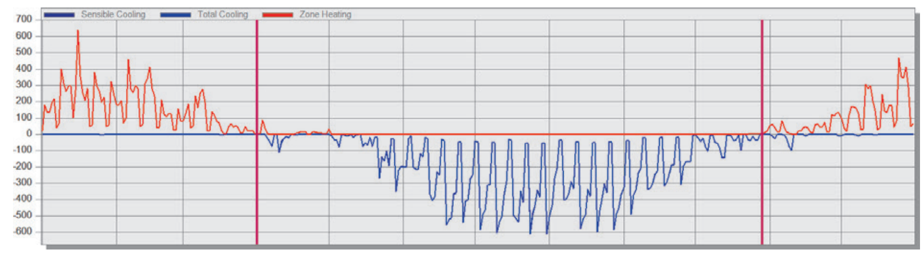


Fig. 88: Sensible cooling and zone heating of the New Generation Office Building

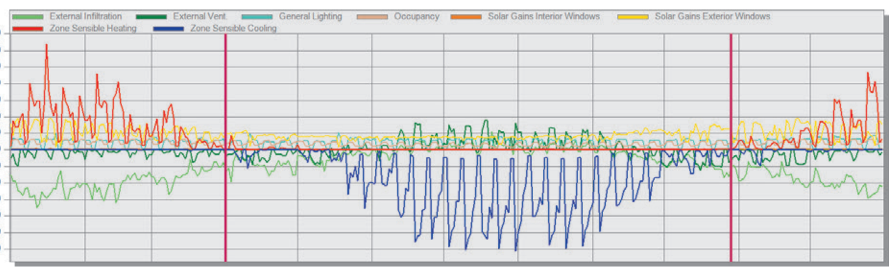


Fig. 86: Daily heat loss and heat gain in the NG Office Building

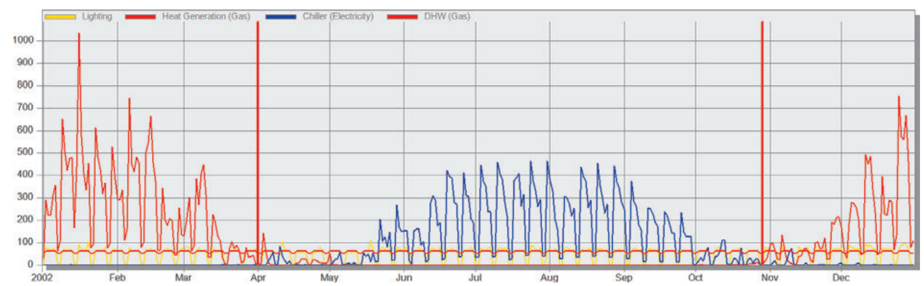


Fig. 89: Daily energy demands of the New Generation Office Building

figure presents the illuminance levels and daylight factors on the third floor of the building on an overcast day in winter.

[11] The HVAC system includes a natural gas heater, a domestic hot water system with a CoP of 0.62 and an electricity-operated cooling system with a CoP of 1.32

The calculation of the building's CO_2 emission rates is based on the amount of energy consumed by the building and the CO_2 emission factors of the different energy carriers.

The energy consumption of the office building is dependent on different factors including the climate, the building's architecture, the materials of the thermal envelope, the HVAC system etc. Hourly weather data is used to define the climate of Hashtgerd New Town for the simulation software tool. Different building components and elements including their individual characteristics affect the energy consumption of the building and thus its CO_2 emissions. The variety of characteristics is broad and ranges from the architectural design, the physical properties of building elements to the building users and their activities.

The energy consumption of the New Generation Office Building is determined through energy simulations. The amount of energy consumed is broken down into the type of fuel. Buildings consume different energy carriers, including renewable energies, electricity and natural gas for cooling, heating, the provision of domestic hot water, lighting and the use of household appliances. In the New Generation Office Building, natural gas is used to generate heat and domestic hot water, whereas electricity is used for cooling, lighting and the operation of office equipment.

The use of renewable energies to cover some of the building's energy demand means that the building produces less CO_2 from fuel combustion. Therefore, if solar thermal panels are used to provide hot water, or if photovoltaic panels are used to cover some of the building's electricity demand, the amount of renewable energies generated by the building must be subtracted from the natural gas and electricity demands. Figure 90 presents the method used for calculating the office building's CO_2 emissions.

The energy demand of the New Generation Office Building for heating, cooling, lighting, domestic hot water and electricity (computers and office equipment) is calculated by performing energy simulations. According to the simulations, the building consumes 155,221 kWh of natural gas and 575,959 kWh of electricity per year.

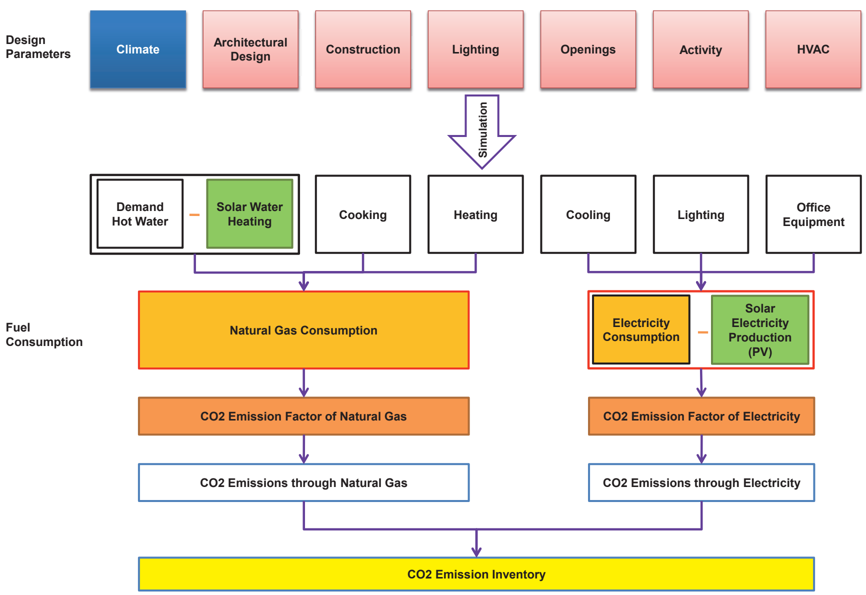
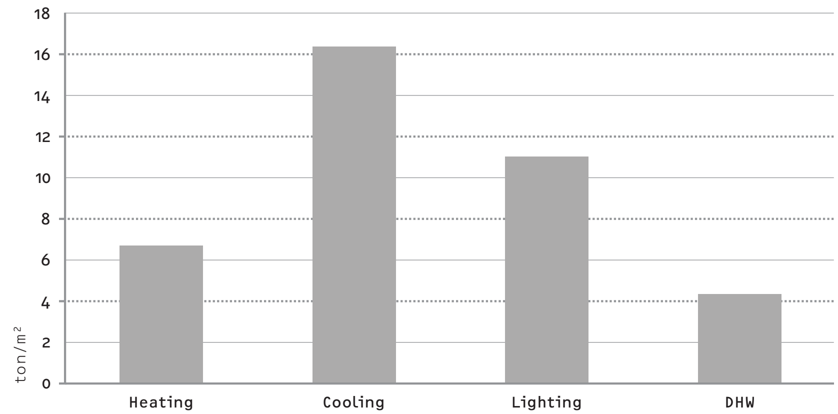


Fig. 90: CO_2 Emission inventory of the New Generation Office Building



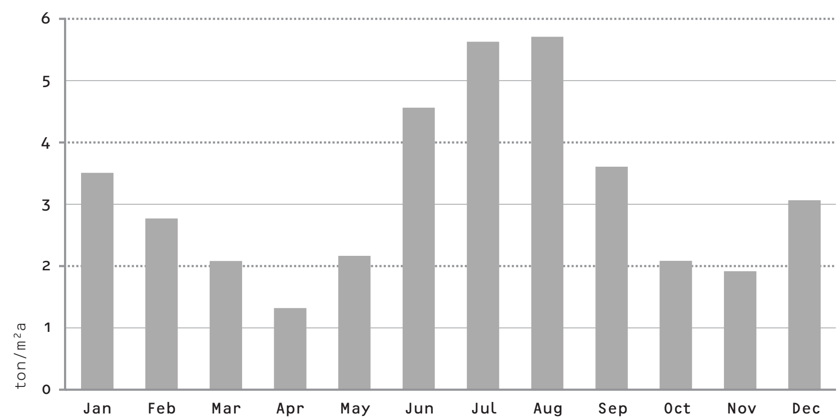


Fig. 91: CO_2 emissions of the NG Office Building according to energy demands

Fig. 92: Monthly CO_2 emissions produced by the energy consumption of the New Generation Office Building

In Iran, the average CO_2 emission factor of electricity between 2007 and 2009 was 0.609 kg/kWh (IEA statistics, 2011). The CO_2 emission factor of natural gas is 0.200971 kg/kWh in Iran (according to IPCC 1996). Based on these factors, the New Generation Office Building emits 381.950 tons[12] of CO_2 per year.

The second method used to determine the CO_2 emission rates of the New Generation Office Building is simulation. Some building energy simulation software tools can also calculate the CO_2 emission rates of buildings. Most of these software tools use the same method as presented in the first process, which considers the CO_2 production to be based on the amount of energy consumed and the CO_2 emission factor of different energy carriers.

The CO_2 emissions of the office building are also determined by performing simulations. As the method of this process as well as the CO_2 emission factor of different energy carriers are identical in the two methods, the results of the CO_2 emissions are also the same. Figure 94 presents the daily CO_2 emissions of the New Generation Office Building, which were calculated by performing simulations.

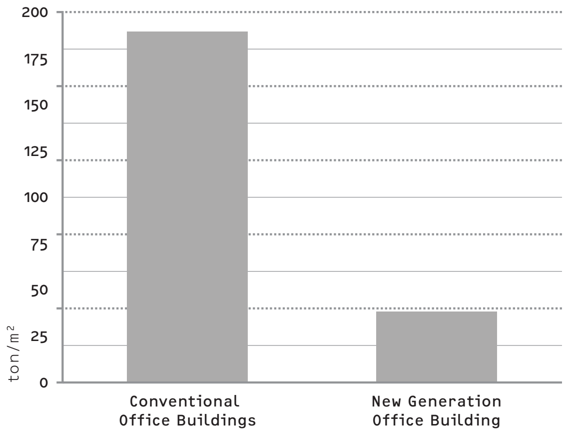


Fig. 93: Comparison of annual CO_2 emissions of New Generation Office Building and conventional office buildings

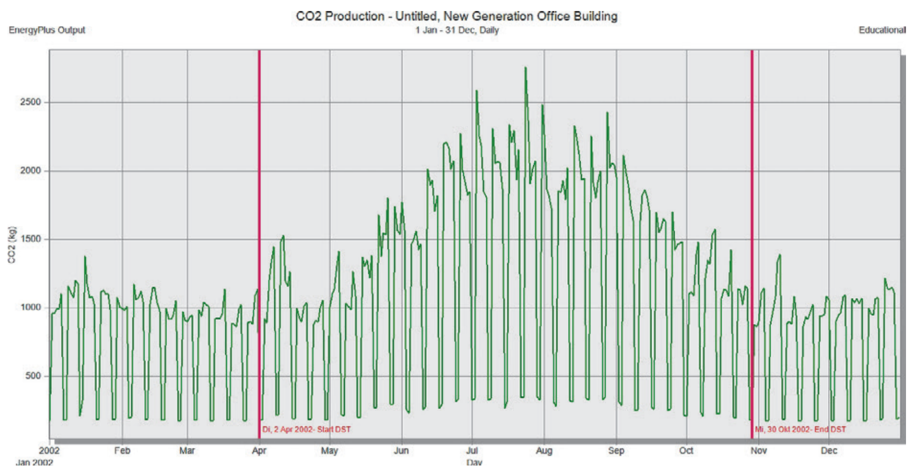


Fig. 94: Daily CO_2 production of the New Generation Office Building

12 The energy demand of the New Generation Office Building (and any other building), and thus its CO2 emissions, change as soon as alterations are made to the building characteristics, such as a change to the physical characteristics of the thermal envelope.

Fig. 95: Site plan

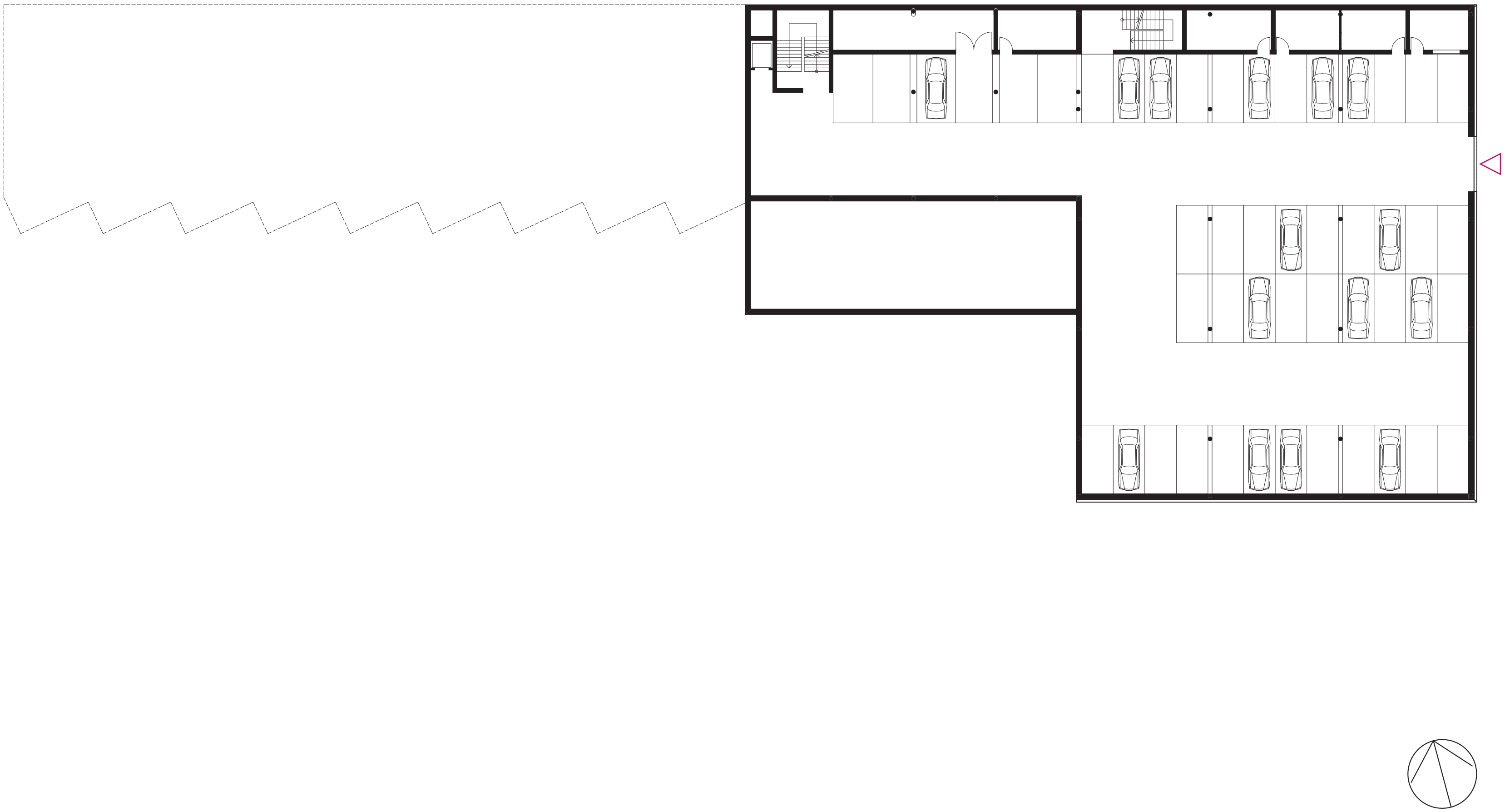


Fig. 96: Underground floor plan of the New Generation Office Building (Scale 1:500)

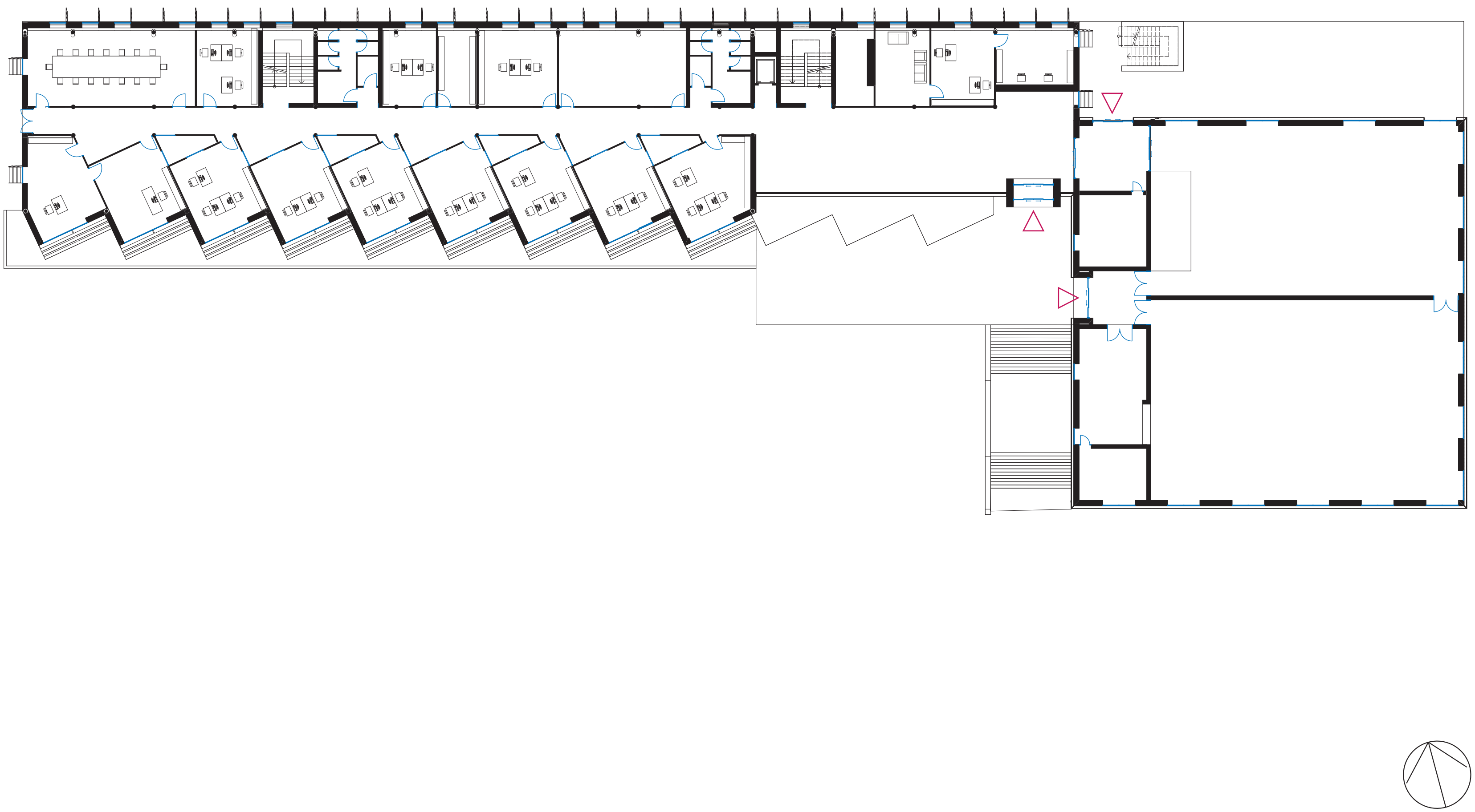


Fig. 97: Ground floor plan of the New Generation Office Building (Scale 1:500)

Fig. 98: First floor plan of the New Generation Office Building (Scale 1:500)

Fig. 99: Second floor plan of the New Generation Office Building (Scale 1:500)

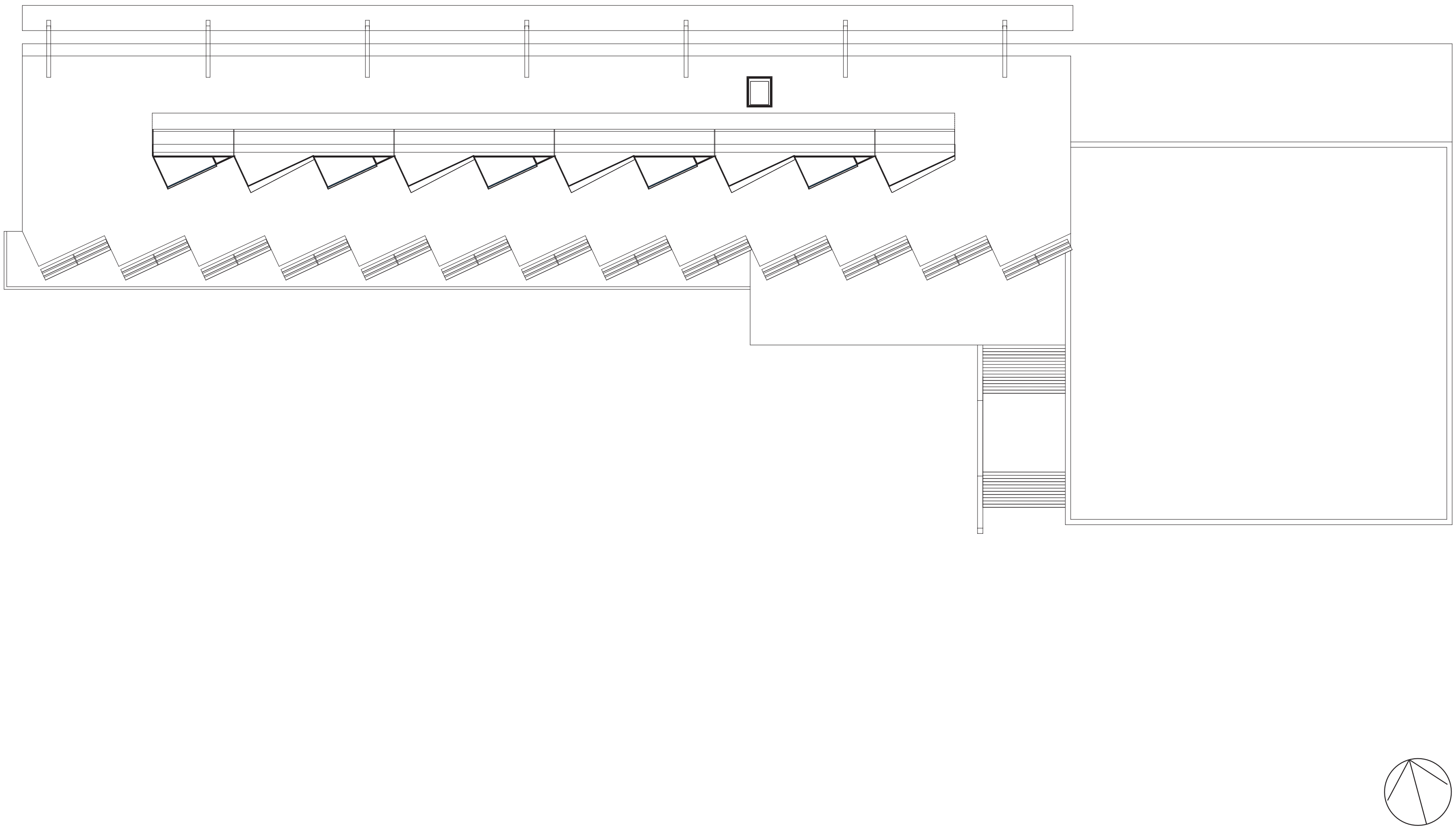


Fig. 100: Roof plan of the New Generation Office Building (Scale 1:500)

Fig. 101: South elevation of the New Generation Office Building (Scale 1:500)
Fig. 102: East elevation of the New Generation Office Building (Scale 1:500)
Fig. 103: West elevation of the New Generation Office Building (Scale 1:500)

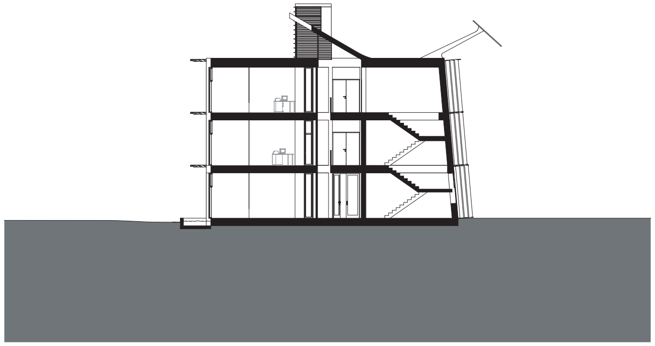


Fig. 104: North elevation of the New Generation Office Building (Scale 1:500)
Fig. 105: North-south section of the New Generation Office Building (Scale 1:500)

Fig. 106: North-south section of the New Generation Office Building (Scale 1:500)

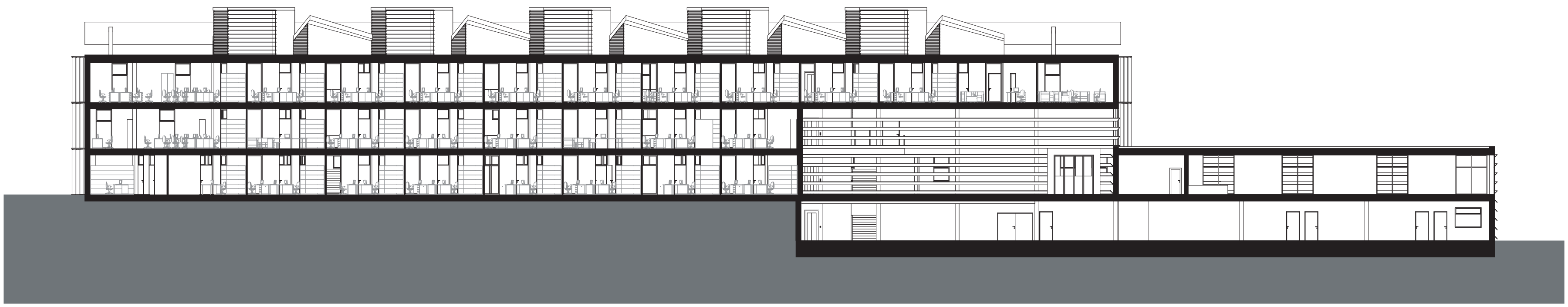


Fig. 107: East-west section of the New Generation Office Building (Scale 1:500)
Fig. 108: East-west section of the New Generation Office Building (Scale 1:500)

Fig. 109: South elevation of the New Generation Office Building (Scale 1:500)
Fig. 110: North elevation of the New Generation Office Building (Scale 1:500)

Fig. 111: East elevation of the New Generation Office Building (Scale 1:500)
Fig. 112: West elevation of the New Generation Office Building (Scale 1:500)

Fig. 113: South view of the New Generation Office Building

Fig. 114: South-east view of the New Generation Office Building

Fig. 115: South-west view of the New Generation Office Building

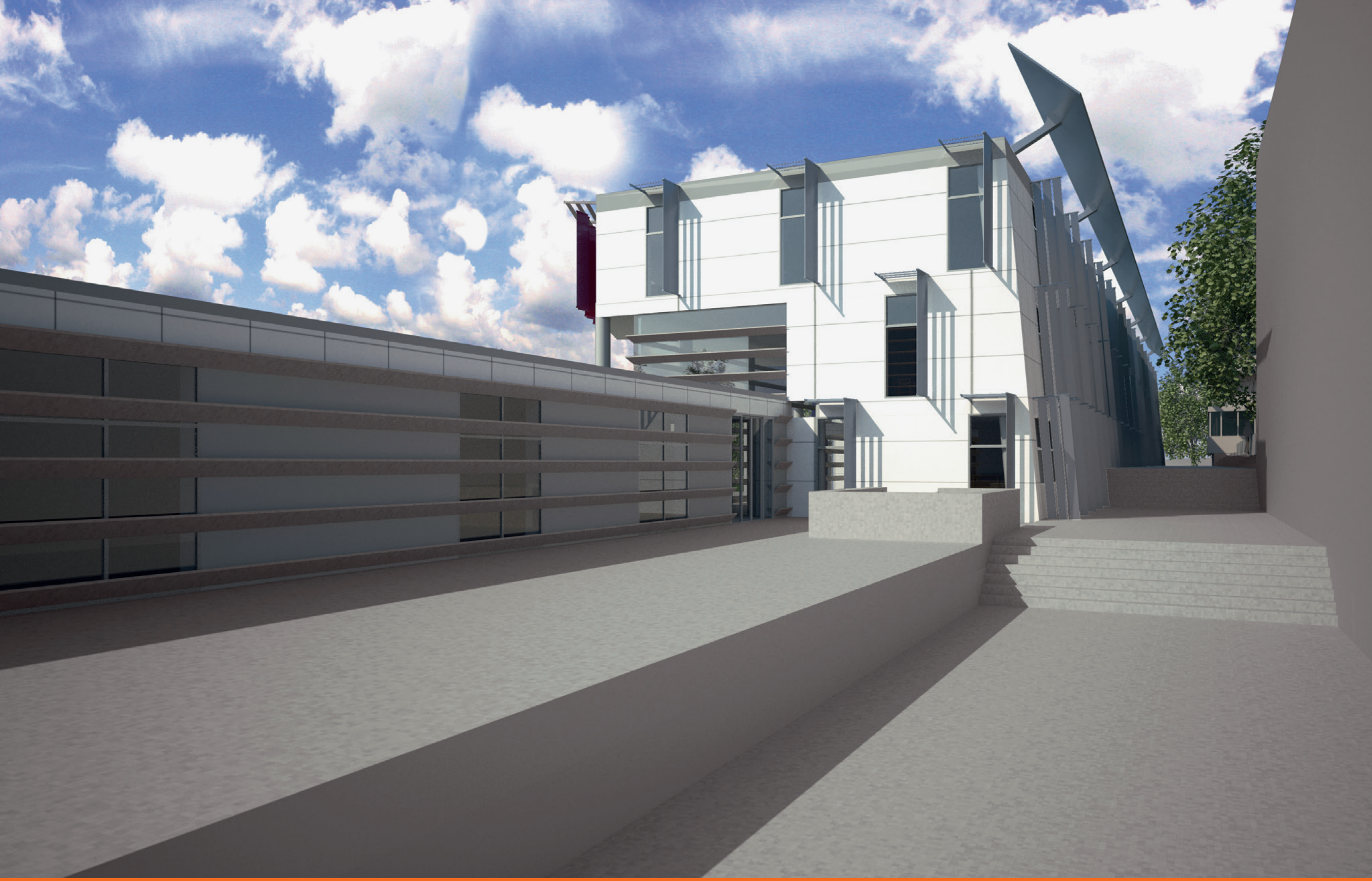


Fig. 116: East view of the New Generation Office Building

Fig. 117: North view of the New Generation Office Building

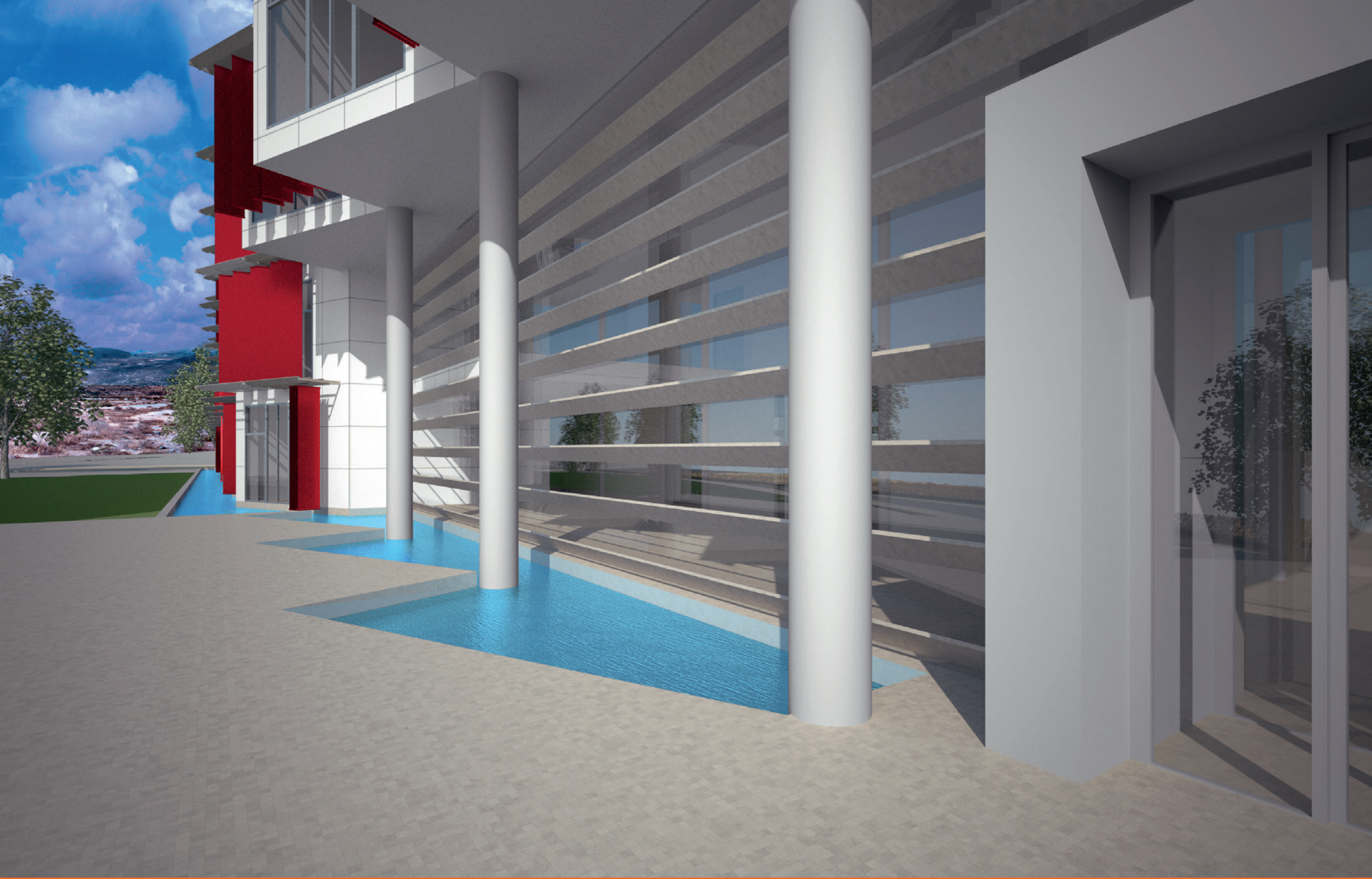


Fig. 118: View into foyer and water surfaces

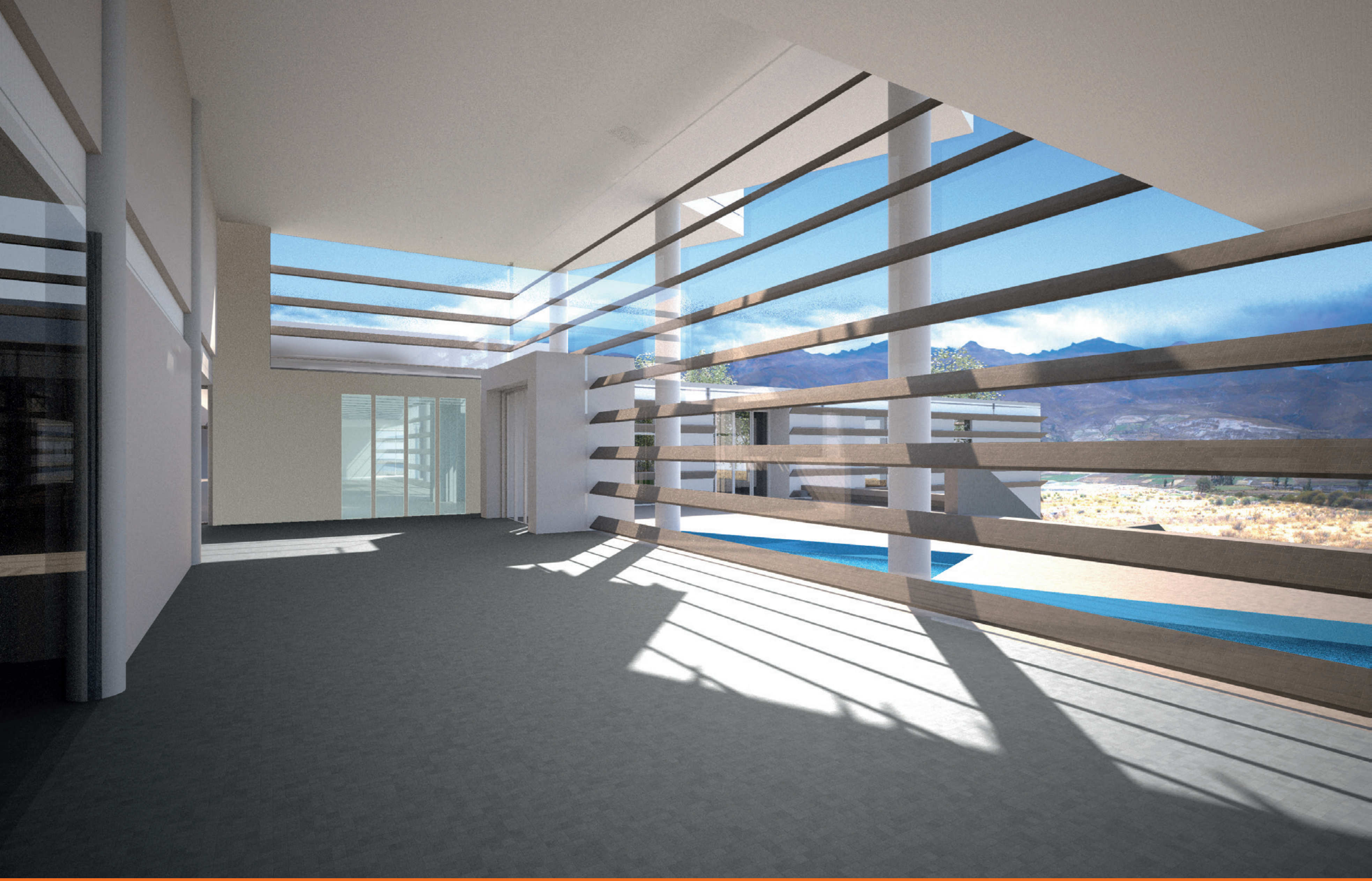


Fig. 119: View into the foyer

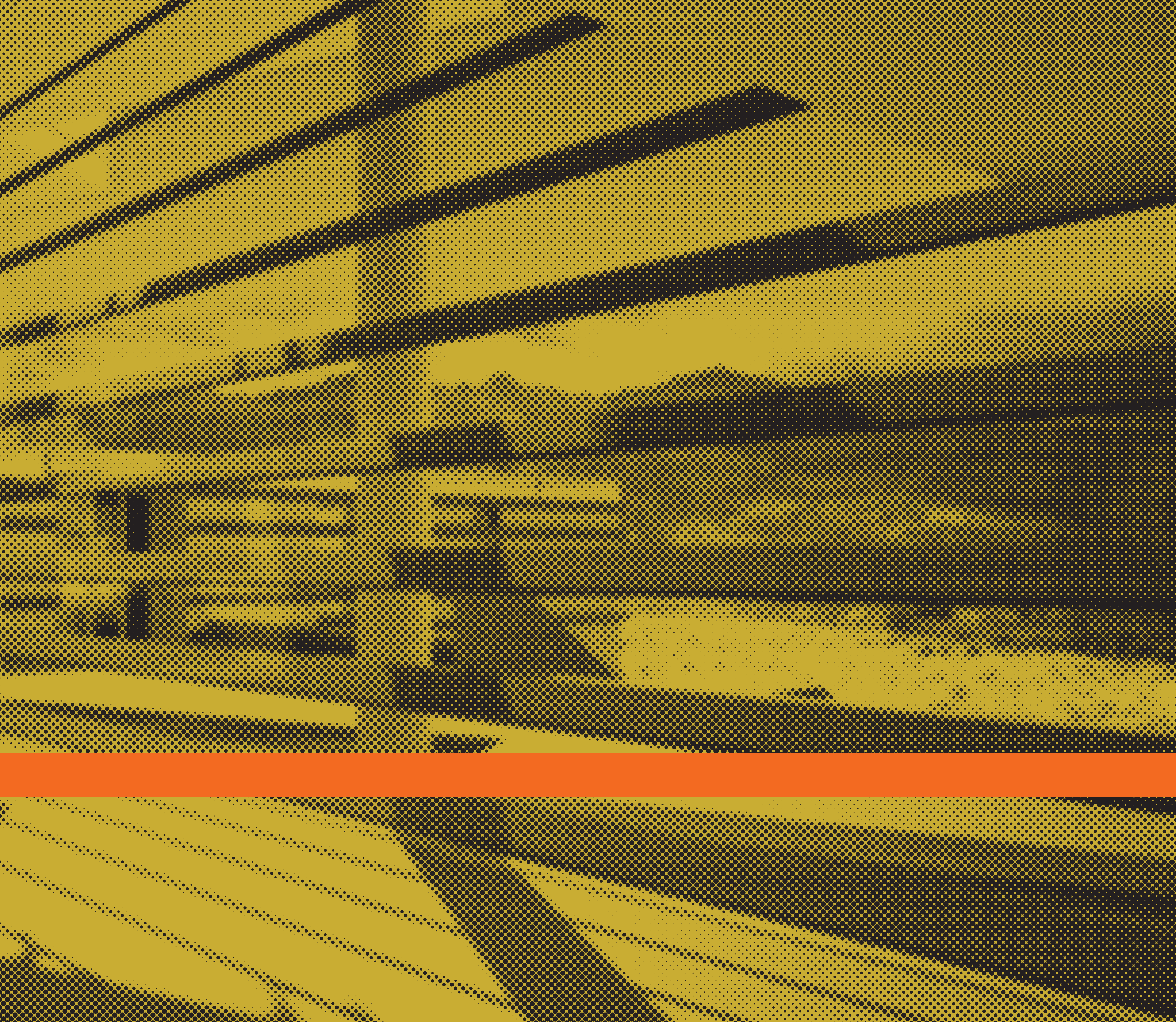
Fig. 120: Daylight provision through skylights

Fig. 121: View into corridor

IV

Energy-efficient Heating and Cooling Systems

Economic Analyses of Solar Heating and Cooling for Office Buildings



1 Introduction

Alongside a building's architectural design and materials of the thermal envelope, the heating, cooling, ventilation and air conditioning (HVAC) systems also affect the final energy demand of a building. The choice of system, and with this the type of fuel that is consumed to provide heating and cooling, influences the building's primary energy demand significantly. Therefore, energy-efficient HVAC systems are indispensable in energy-efficient buildings. A proportion of the energy consumed by the heating and cooling system can be supplied by a renewable system. This clearly decreases the primary energy demand of the building, but increases the initial costs.

The selection of a HVAC system depends on different factors, including the climatic conditions, the building type and its heating and cooling loads as well as the economic situation.

This study investigates the energy and cost efficiency of heating and cooling systems for energy-efficient office buildings in the climate conditions of Hashtgerd New Town. As Hashtgerd is a place with a continental climate both heating and cooling are required. If a system is installed which can provide both heating and cooling, the amount of system equipment is decreased and with this the initial cost. Heat pumps, for example, can generate both heating and cooling, but they have a high primary energy demand. The second possibility is to use two different systems for heating and cooling. Both possibilities are presented in this study.

The New Generation Office Building is used for research purposes in this project. Therefore, the heating and cooling design calculations are carried out for precisely for this building to estimate the size of heating and cooling equipments required to meet the coldest winter and the hottest summer design weather conditions in Hashtgerd New Town. The Figures 122, 123 and 124 show the heat balance in the New Generation Office Building for the coldest winter and the hottest summer design weather conditions.

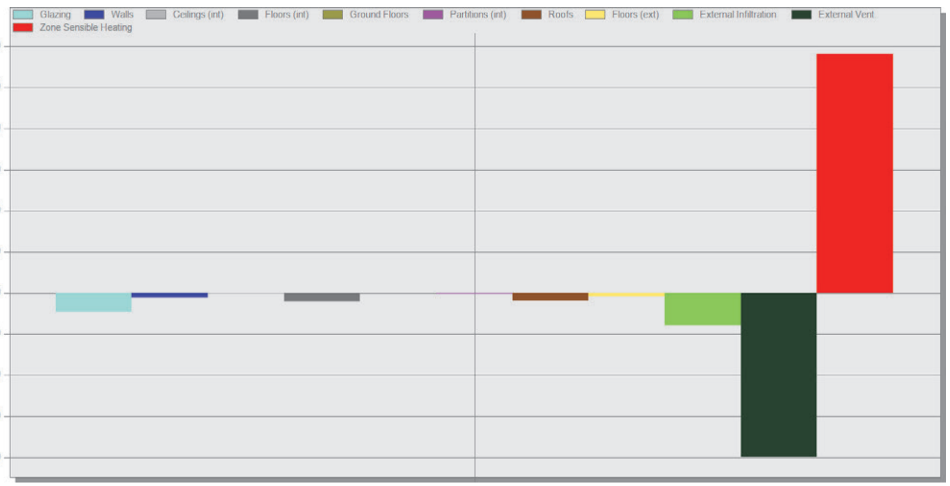
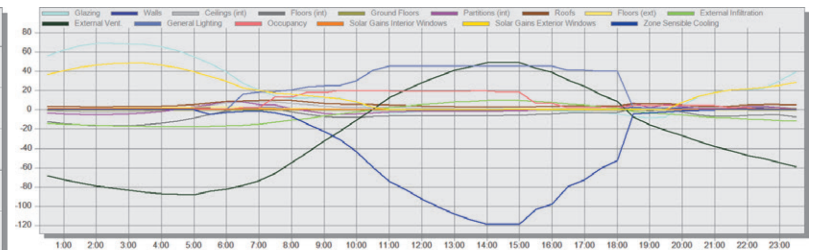


Fig. 122: Heat loss and gain in the New Generation Office Building in winter (kW)



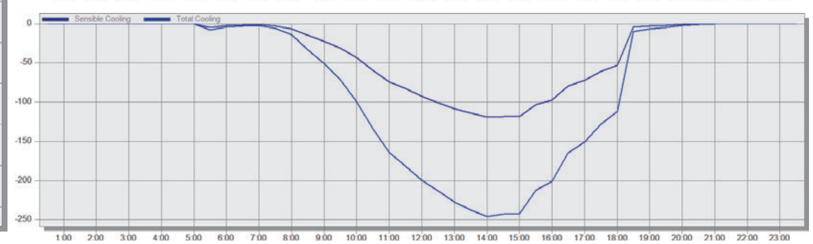


Fig. 123: Heat loss and gain in the NG Office Building in summer (kW)
Fig. 124: Sensible and total cooling capacity in the New Generation Office Building in summer (kW)

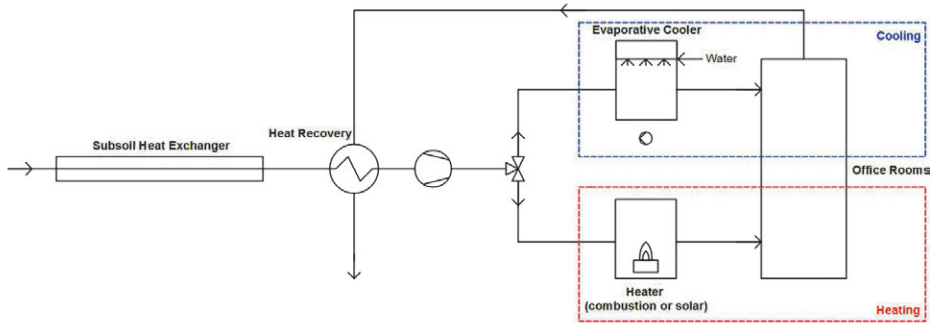
2.1 Heating

In this solution, a combination of subsoil heat exchanger and gas heater is utilized to heat the rooms. Cold outside air is drawn in through the subsoil heat exchanger pipes and heated due to the higher subsoil temperatures. The air is then heated further in an air-to-air heat exchanger, which recuperates heat from the warm waste air before it leaves the building. A gas heater is used to meet the necessary room temperature. After supplying the rooms with thermal energy, the waste air exits the building by passing through the mentioned air-to-air heat exchanger.

2.2 Cooling

As the studies in Chapter I show, almost the whole cooling demand can be covered by an evaporative cooling system because of the low relative humidity in Hashtgerd New Town. Due to the fact that no energy is required to generate cold in an evaporative cooling system and the cooling is only based on the evaporation of water, the system consumes much less energy than a refrigeration system. An evaporative cooling system only requires water and electricity to operate the fans and pumps. The application of an air-to-air heat exchanger to recover heat from the waste air as well as a subsoil heat exchanger for precooling the supply air can reduce the building's cooling demand and thus the electricity and water demand of the evaporative cooling system.

To cover the cooling needs of the building, almost the same system as for heating is used. Warm outside air is drawn in through the subsoil heat exchanger and cooled due to the lower subsoil temperatures. The air is then further cooled by the air-to-air heat exchanger with cold waste air that exits the building. To meet the final temperature that is needed in the rooms, the air passes through an evaporative cooler. In the cooler unit, water evaporates into the passing dry air and reduces the temperature. After supplying the rooms with cold, the air leaves the building through the air-to-air heat exchanger.



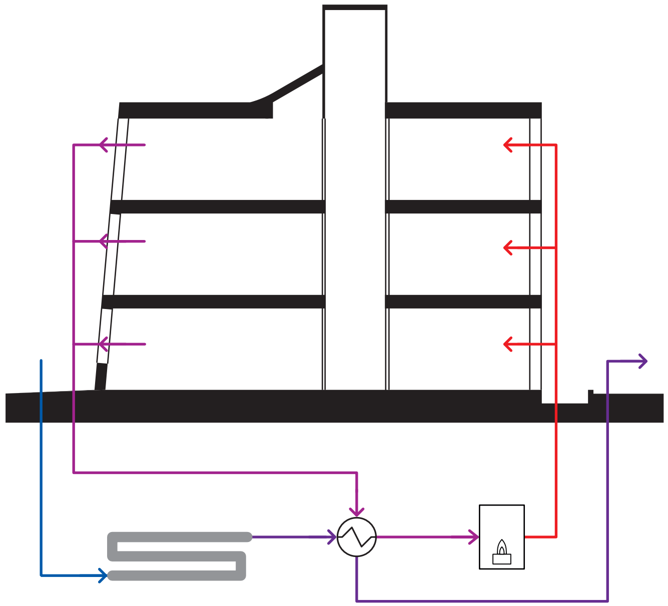


Fig. 125: Heating system in the New Generation Office Building with an air-to-air and subsoil heat exchanger

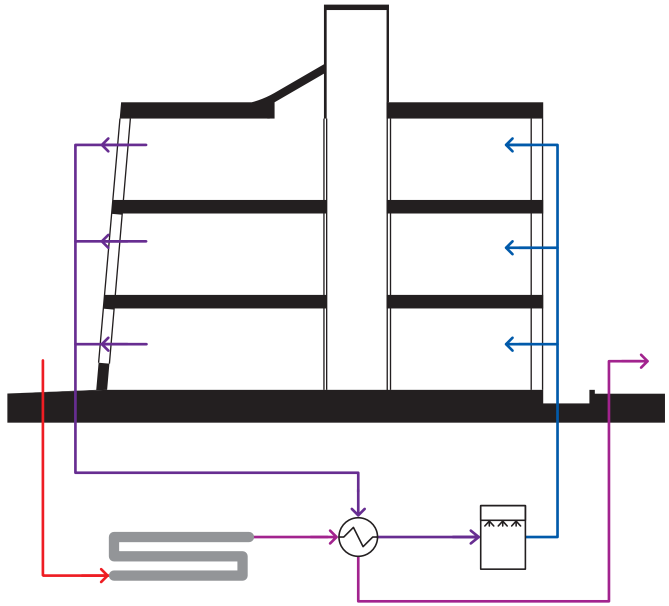


Fig. 127: Heating and cooling systems in the New Generation Office Building with an air-to-air and subsoil heat exchanger | Fig. 126: Evaporative cooling system in the New Generation Office Building with an air-to-air and subsoil heat exchanger

3 Solar Heating and Cooling Systems

Iran's richness in natural resources is often mentioned as the country's chance for economic prosperity. What often appears to be ignored, though, is the country's overwhelming supply of renewable resources.

With an average hourly global horizontal radiation of 462 Wh/m² in Hashtgerd New Town (Source of Weather Data: Meteonorm 6), the potential for solar energy technology is very high. In Germany, for instance, which is one of the world's top photovoltaic installers, the annual irradiation in Munich, as an example city, is only about 275 Wh/m² (IWEC). Figures 126 and 127 show the daily direct normal and diffuse horizontal solar radiation in Hashtgerd New Town and Munich as an example city in Germany. A comparison of these two graphs shows that the solar radiation is Hashtgerd New Town is much higher than in Munich, which indicates the high potential of solar systems in this city.

Due to its climatic conditions, Iran is provided with both, high solar irradiance and a large number of sunshine hours, up to 2,800 h/a (Heinrich Böll Foundation, 2005). However, since prices for fossil fuels are still relatively low in Iran, even after reduction of energy subsidies, the economic viability of a solar energy system, instead of conventional system, is not always given. Due to the fact that photovoltaic systems are expensive in the present economic conditions of Iran and the installation of the solar panels is economically not viable, this study focusses on the application of solar thermal systems.

Not only can solar systems be applied for heating the building and for supplying domestic hot water, they can also be used for cooling. The amount of solar radiation is high during the day in summer, which means that solar radiation is available precisely when the building requires cooling. The amount of solar radiation incidence is directly related to the amount of cooling energy demand. Therefore, solar collector systems are suitable systems for cooling.

This study investigates the application of an innovative solar thermal system for heating and cooling in office buildings from an economic and technical viewpoint in Iran. The intention is to find an answer to the question of whether a solar thermal system is economically and technologically feasible in office buildings and how the area of the solar collector, the size of the buffer tank as well as the slope of the collectors affect the cost-efficiency of these systems. This study is also intended to determine the optimum area of the solar collector, the size of the buffer tank and the slope of the panels for the New Generation Office Building, which is used as a case study.

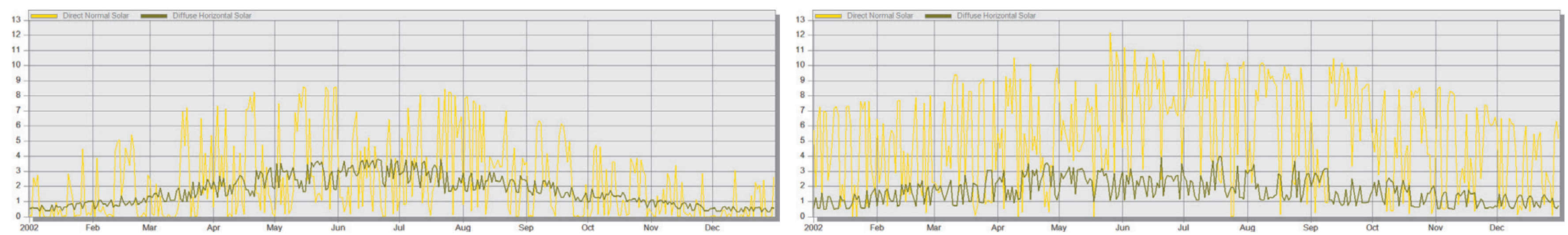


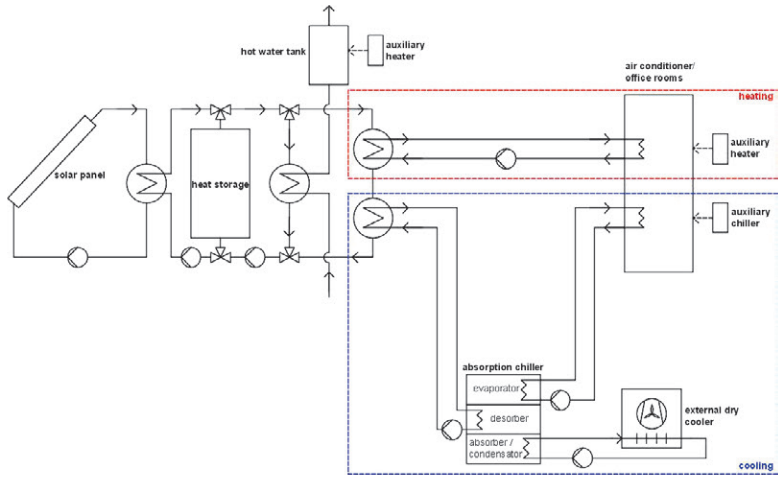
Fig. 128–129: Daily direct normal and diffuse horizontal solar radiation in Hashtgerd New Town and Munich (Wh/m²) (Source of Weather Data: Meteonorm 6 and IWEC)

3.1 Solar thermal system

The necessary thermal energy will primarily be supplied by the sun. A working fluid is heated in the solar thermal panels through solar radiation. The hot fluid then releases the heat to the heating system of the building. Excess heat from the solar panels is stored in a solar heat storage system (e.g. a buffer tank), from which it can be withdrawn in times of insufficient solar irradiance. The building needs a back-up heater (e.g. gas heating system, boiler, etc.) for the heating system in periods with insufficient solar radiation or when insufficient heat remains in the solar heat storage tank.

The cooling energy for the building is supplied by solar thermal energy by making use of an absorption refrigerator. An absorption refrigerator is a device that uses a heat source (e.g. solar energy, kerosene-fueled flame, waste heat from factories or district heating systems) to provide the thermal energy required to operate the cooling system.

A working fluid is heated in the solar thermal panels through solar radiation. The fluid is circulated through the absorption chiller which utilizes the heat to generate cooling energy. The chiller mainly consists of



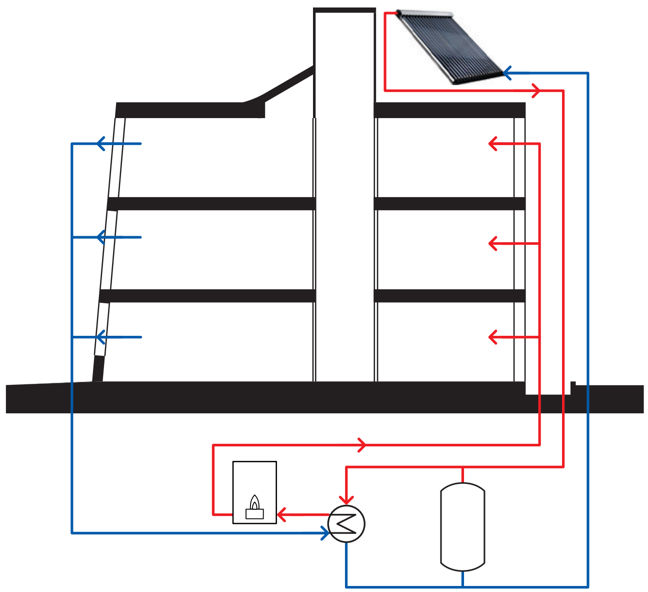


Fig. 130: Solar heating system in the New Generation Office Building

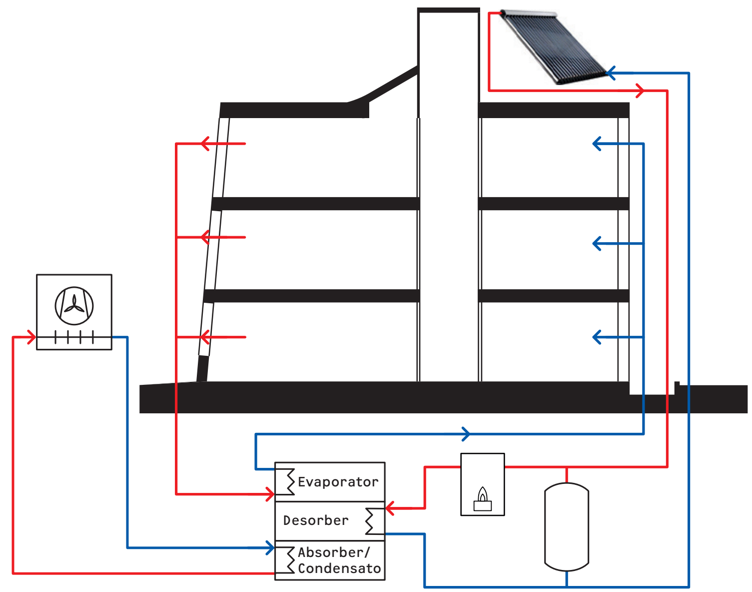


Fig. 132: Solar heating and cooling systems in the NG Office Building
Fig. 131: Solar cooling system in the New Generation Office Building

three parts: the desorber unit, the absorber-condenser unit and the evaporator unit. The hot fluid from the solar panels releases the thermal energy in the desorber and is then returned to the solar panels to be reheated. In the evaporator unit, a second fluid is cooled and circulated to the building's HVAC system where the cooling energy is released to cool the rooms. From a thermodynamic perspective, the thermal energy has to be extracted from the absorption chiller, which is performed by the absorber-condenser unit. Its working fluid is cooled by an external recooling unit. Similar to the heating system, the excess thermal energy from the solar panels is not wasted, but stored in a heat storage system (e.g. a buffer tank) from which it can later, in times of insufficient solar irradiance, be withdrawn. In times of insufficient thermal energy, an empty heat storage tank or a lack of solar radiation, the absorption chiller is backed by a boiler, which supplies thermal energy to the desorber unit.

3.2 The f-chart method

Unlike conventional heating and cooling systems that are run on permanently available energy sources (e.g. gas, grid electricity), a solution which integrates solar energy is much more complex in its design due to the fact that its performance is vastly dependent on the volatile supply of solar radiation and the location's climatic conditions. Nevertheless, to highlight the effectiveness of solar power, the system's performance must be determined. To avoid time-consuming simulations of each system, it is possible to make use of the f-chart method (derived from the solar ratio f), which helps to approximate a solar thermal system's performance with a few assumptions. The f-chart method is internationally acknowledged and widely used. It is a semi-empirical method that uses, on the one hand, actual on-site parameters (e.g. latitude or climate data) and, on the other hand, performance data from over a hundred analyzed solar thermal systems. It helps the system designer to predict the solar system's performance without having to model and simulate the detailed physics. The following table shows the main input parameters for the f-chart method.

The f-chart method uses these parameters to predict the monthly solar yield of a system. The f-chart method was initially invented for solar heating systems; however, it can be extended to make fairly accurate predictions of solar thermal cooling systems. There are several reasons to support this assumption. Firstly, a single-stage absorption chiller works at the same temperature as a heating system. Secondly, an office building's cooling demand generally follows that of the heating demand during the course of a day. Moreover and most importantly, the absorption chiller's Coefficient of Performance is a constant value and almost independent of the machine's partial load (Ursula Eicker, 2009). So the building's monthly cooling demand can easily be translated into a virtual heat load, which can then be processed with the f-chart method.

Location parameters	System parameters
•• Geographical latitude	•• Optical efficiency of the collector
•• Monthly average of daily global horizontal radiation	•• Coefficient of heat transmission of the collector
•• Monthly average of daily diffuse radiation	•• Collector slope
•• Monthly mean outside temperature	•• Absorber area of collector
	•• Reference temperature of the collector
	•• Volume of the hot water buffer tank
	•• Monthly heating demand of the building

Tab. 17: Main input parameters for the f-chart method

3.3 Application to the New Generation Office Building

Applying the f-chart method to the New Generation Office Building helps to make first approximations of a solar heating and/or cooling system for the building. The building's monthly heating and cooling demand are determined by performing physical simulations of the building using the program DesignBuilder. For the sake of consistency, the same weather data (temperatures and radiations) that was used in the DesignBuilder simulations is also used in the f-chart method.

Figure 133 shows the building's monthly heating demand and the thermal energy demand of the absorption chiller to cover the building's cooling energy demand. It also contains the solar ratio, which was calculated with the f-chart method (in the case of vacuum tube absorbers), and thus the solar energy yield. The diagram illustrates that the solar system, with parameters from table 18, can almost cover all the heating and cooling energy demands from October to May, but is inadequate to cover the cooling loads in the summer months.

Parameter	Value	Unit	Source
General			
COP of absorption chiller	0.70	kWh_{cold}/kWh_{heat}	Henning, 2004
Geographical latitude of Hashtgerd New Town	35.96	degrees	GoogleMaps
Specific buffer tank volume[1]	35.00	liters/m²	Khartchenko, 2004
Solar thermal collector			
Optical efficiency	(flat plate) 0.73 (vacuum tube) 0.80	–	Quaschning, 2009
Heat transfer coefficient	(flat plate) 1.70 (vacuum tube) 1.10	W/m²K	Quaschning, 2009
Collector slope	20.00	degrees	predefinition
Collector area	300.00	m²	predefinition
Reference temperature of collector	70.00	degrees celsius	predefinition
Collector azimuth	(south) 0.00	degrees	predefinition

Tab. 18: Parameters of the solar system for the New Generation Office Building

3.4 Economic assessment

An energy system must be profitable throughout its life cycle. Whereas solar energy is free of charge, the initial investment costs of a solar system are usually higher than those of a conventional energy system, which in contrast has higher operating costs due to the fuel it runs on. This issue—high investment and low operating costs or low investment and high operating costs—must be analyzed thoroughly using an appropriate method.

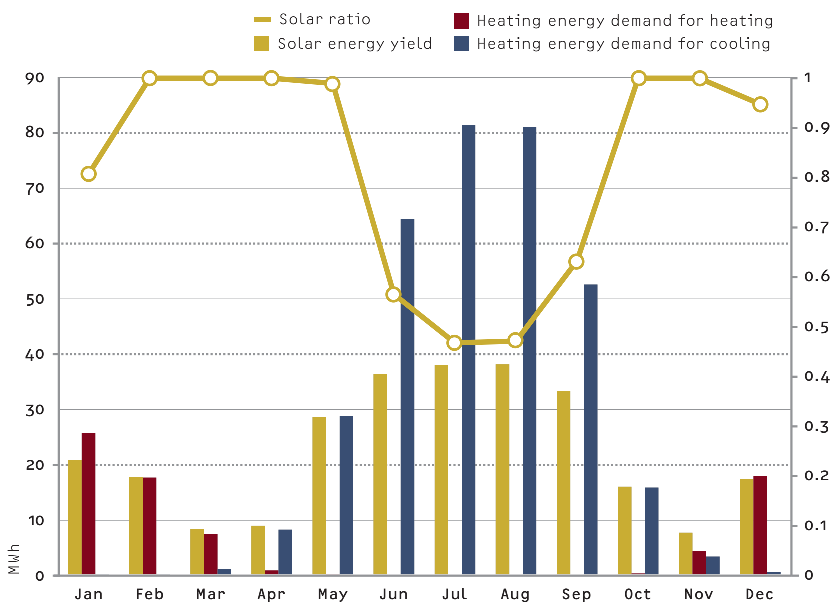


Fig. 133: Building's energy demands, solar yield and solar ratio

Parameter	Value	Unit	Source
General			
Economic life-time	20	years	assumption
Effective rate of interest	15	%	Central Bank of Iran, 2012
Rate of inflation	15	%	International Monetary Fund, 2012
Rate of real price increase (all)	−5	%	Iranian Ministry of Energy, 2012
Natural gas rate (1st year)	0.04	EUR/kWh	assumption
Electricity rate (1st year)	0.09	EUR/kWh	Iranian Ministry of Energy, 2012
Solar thermal equipment cost			
Auxiliary heater	35,000	EUR	DBI Gas- und Umwelttechnik, 2011
Specific cost of solar collectors	(flat plate) 200 (vacuum tube) 400	EUR/m² EUR/m²	Quaschning, 2009
Specific cost of buffer tank	3	EUR/liter	Quaschning, 2009
Absorption chiller	67,000	EUR	Eicker, 2006
Re-cooling unit	30,000	EUR	Guentner AG & Co. KG, 2011
Technical data			
COP of compression chiller	4	kWh_{cold}/kWh_{heat}	Eicker, 2006
Efficiency of auxiliary heater	90	%	Recknagel, 2012
Specific electricity consumption of recooling unit	8	$Wh_{el}/kWh_{re\text{-}cool}$	Recknagel, 2012

Tab. 19: Economic parameters

The annuity method, as described in the German VDI guideline 2067 (09/2000), part 1, is used to assess the possibility of investing into the described energy system. It is a dynamic method that helps estimate an energy system's long-term marginal cost in consideration of the cost of capital, the inflation rate and price increases. In order to evaluate the solar system's profitability, a second alternative heating and cooling system is assessed to compare the costs. The second system is a conventional one. A combustion process using natural gas is used to supply heat; the cooling is covered using a compression chiller and electricity. This analysis only considers the investment costs of the main system components and the fuel costs, since the investment costs of accessory equipment and maintenance is thought to be about the same for both solutions. The auxiliary heater used in the solar thermal system is the same heater that is used in the conventional heating solution. Since a compression chiller works at a higher coefficient of performance (CoP) than an absorption chiller, the re-cooling unit can be smaller and thus less costly, which is why another value will be assigned than that of the re-cooler for the solar thermal solution.

The data for these calculations is obtained from different sources. The economic factors, such as inflation and interest rates as well as the energy costs, apply to Iran. Because of a lack of information concerning equipment prices in Iran, these costs are based on prices in Germany. However, the prices for solar collector systems would most probably be lower in Iran, which means that the economic efficiency of this study is falsely increased.

3.4.1 Results

The results of the economic assessment (in the case of vacuum tube collectors) show that is not profitable to install a solar system for heating and cooling purposes, at least not with the chosen system parameters. Figure 134 compares the long-term marginal cost[2] of both the solar solution and the conventional solution. The cost per kWh (heating or cooling energy) is approximately 0.18 EUR in the case of the solar system and 0.09 EUR in the case of the conventional system (consisting of 0.15 EUR/kWh for heat from the conventional heating system and 0.07 EUR/kWh for the cooling energy from the conventional cooling system).

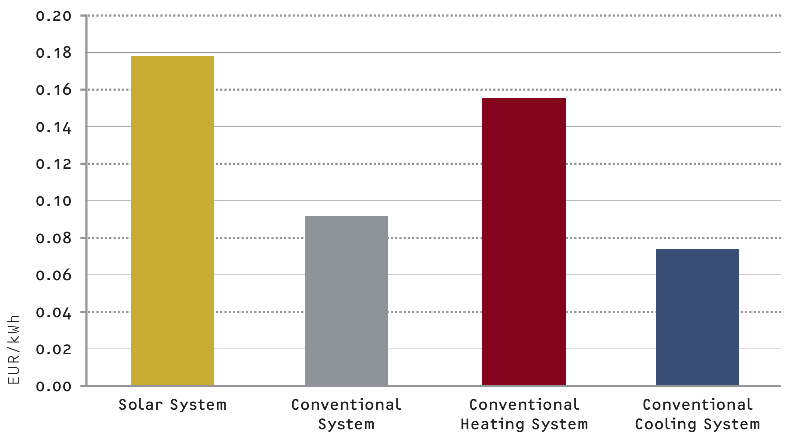


Fig. 134: Comparison of long-term marginal cost of solar and conventional HVAC systems

3.5 Sensitivity analysis

Due to the fact that the area of collectors can influence the cost efficiency of the system, the relationship between the area of collectors and long-term marginal cost is studied. The relationship is illustrated in figure 135. This study also shows the optimum collector areas for minimum long-term marginal cost.

Because the system's energy costs depend to a great extent on the determined parameters, it is advisable to carefully analyze the influence of these on the system's performance. Figure 135 displays the relation between long-term marginal cost (LTMC) and different solar collector areas. The graph shows that the specific energy costs can be reduced to approximately 0.17 EUR/kWh if an area of around 100 m² is applied. However, 0.17 EUR/kWh is still much higher than 0.09 EUR/kWh that applies for a conventional system.

Another factor that affects the cost efficiency of the whole system is the size of the buffer tank. To determine whether the size selected for the buffer tank is sufficient, figure 136 shows the LTMC per m² of collector area and buffer tank size. The diagram shows that a buffer tank size of 35 l/m² collector area is ideal from an economic point of view. Any volume greater than this increases the investment costs to such an extent that the system is no longer able to compensate for these with energy savings.

The angle of the panels influences the amount of incident solar radiation at different times of the day and year. Due to the different solar altitude angles in summer and winter, the collectors that are used only for heating (in winter) and which are used both for heating and (solar) cooling (both in winter and summer) must have different slopes in order to provide the highest coverage rate for the required thermal energy. As the slope of the collectors affects the incident solar radiation and thus the system efficiency, it also influences the long-term marginal cost of the supplied energy. Figure 137 illustrates the long-term marginal cost in re-

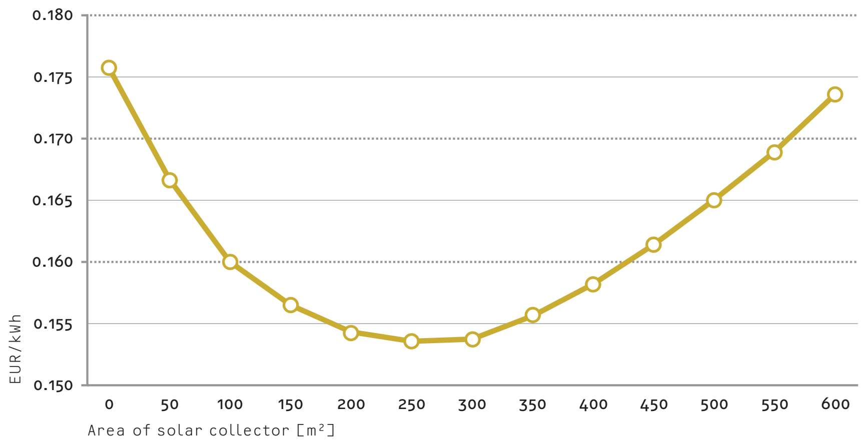
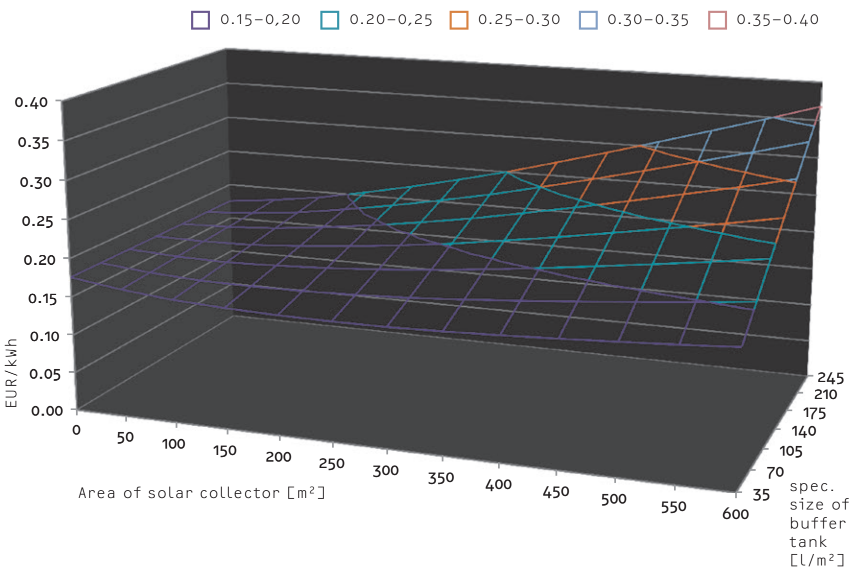


Fig. 135: Long-term marginal cost per m² of collector area



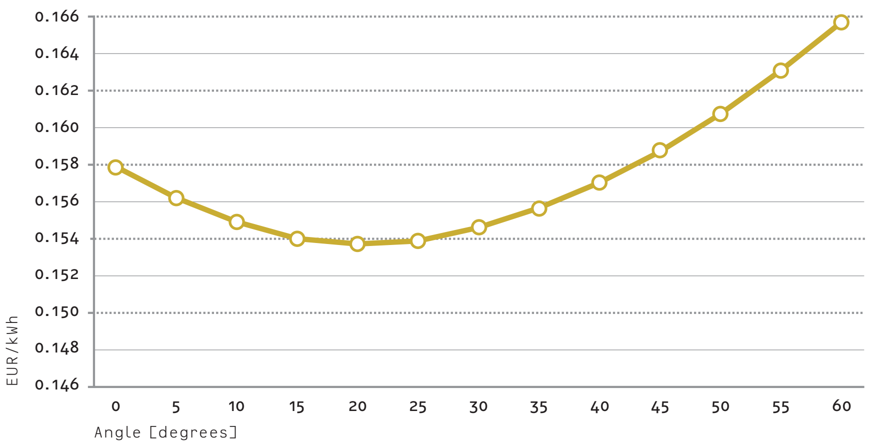


Fig. 136: Long-term marginal cost per m² of collector area and buffer tank size
Fig. 137: Long-term marginal cost per degree of collector angle

lation to the inclination of the solar collectors in order to understand the importance of choosing the right positioning of the solar collectors. The diagram demonstrates that any inclination smaller or greater than 20 degrees increases the system's costs. This can be explained by the collector's solar energy yield which is strongly dependent on the collector's angle in reference to the sun.

4 Conclusion

The economic analyses concerning the application of solar heating and cooling systems show that it is reasonable to make use of a combined solar heating and cooling system from a technical viewpoint, not however from an economic viewpoint. The long-term marginal cost of at least 0.17 EUR/kWh with vacuum tube collectors (0.15 EUR/kWh with flat plate collectors) are much higher than those of the conventional reference system. There are two reasons for this: firstly, the solar solution involves much higher capital costs due to the fairly expensive equipment and the high interest rate on borrowed capital in Iran; secondly, the energy sources a conventional system runs on (electricity and natural gas) are inexpensive in Iran, which keeps the operating costs of this heating and cooling system very low, and thus makes it very competitive, even in the long term.

Whether a partial solar solution (either only solar heating or solar cooling, both with the addition of a complimentary conventional system) can compete economically with the fully conventional solution has not been examined, but will be subject to further investigations. It must also be noted that solar cooling using thermal processes is only one possible method; the alternative would be a combination of a photovoltaic system and a compression chiller using either the local grid or a battery storage system as a buffer for the volatility of solar irradiance.

From an economic point of view, the installation of a gas heater for heating and an evaporative cooling system for cooling is more suitable for office buildings in the current economic conditions of Iran. But in order to decrease the heating and cooling demands of the building and install a smaller HVAC system, a subsoil heat exchanger is a good solution to support both systems by preheating and precooling the supply air. The installation of an air-to-air heat exchanger can also minimize the heat loss and energy demands of the mechanical ventilation system both in winter and summer.

[1] Standardized for solar thermal collector area
[2] Long term marginal energy cost (LTMC) includes all system expenses (capital cost, operating costs, etc.).

V
Appendix

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About the Author

Farshad Nasrollahi was born in 1977 in Shahrekord, Iran. He completed secondary education at a school for brighter pupils in Borujen, where he received a diploma in 1995 in the field of mathematics. In 2002, he obtained a Master of Arts in Architecture from the Faculty of Arts and Architecture at the Yazd University in Iran. His thesis won the highest rank in the first Festival of Architecture and Urbanism organized by the Faculty of Fine Arts at Tehran University and the Art Academy. Following his time as a student, Farshad Nasrollahi worked as a lecturer in the departments of Architecture and Civil Engineering in Iran for four years.

At the end of 2004, he started his PhD studies at the Berlin Institute of Technology, where he received a Doctor of Engineering in the field of Energy and Architecture in 2009. The title of his research was: Climate and energy responsive housing in continental climates. In the meantime, he has worked as a research assistant at this university for some periods between 2006 and 2008. He received the DAAD Prize 2009 for the outstanding achievements made during his studies. His dissertation received the "Best PhD Dissertation Award in the field of Energy Conservation" from the Iranian National Energy Committee, IFCO, which is affiliated to the Ministry of Petroleum and IEEO, an affiliation of the Ministry of Energy.

Since 2008, he has worked as a full-time assistant professor in the Chair of Building Technology and Architectural Design. This Chair connects building technology and design and forms—in the fields of teaching and research—an interface between the various engineering disciplines and the architect in an integrated design process.

The main research filed by Farshad Nasrollahi within this Chair and the Young Cities Research Project has been energy-efficient building. He has also worked as a member of the editorial group of the Young Cities Research Paper series, which has published the results of the research project in eight consecutive volumes.

His teaching activities at the Berlin Institute of Technology focus on building energy simulation and energy-efficient architecture. He has worked as a teacher at the TU Berlin Campus El Gouna, Egypt, the Isafahn University of Arts and Ilam University, Iran.

Farshad Nasrollahi was awarded the "Best Energy Researcher of the Year 2011" by the Iranian Petroleum and Energy Ministries. He has also published several books and many scientific papers in the field of architecture and energy. Since August 2013, he has been working as an assistant professor at the Berlin University of Arts.

Universitätsverlag der TU Berlin
ISSN 2193-6099 (Print) ISBN 978-3-7983-2578-4 (Print)
ISSN 2193-6102 (Online) ISBN 978-3-7983-2579-1 (Online)

BHRC
Road, Housing & Urban Development Research Center
ISBN 978-600-5392-82-1