young cities
Developing Urban Energy Efficiency
Tehrān-Karaj

09

Young Cities Research Paper Series, Volume 09

Intelligent Design using Solar-Climatic Vision

Energy and Comfort Improvement in Architecture and Urban Planning using SOLARCHVISION

Mojtaba Samimi, Farshad Nasrollahi

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BHRC

Young Cities Research Paper Series, Volume 09
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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Development Research Center
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 978-3-7983-2675-0 (Print)
ISBN 978-3-7983-2676-7 (Online)

ISBN 978-600-113-113-4

Simultaneously published online on the Digital Repository of the Technische Universität Berlin
URL http://opus4.kobv.de/opus4-tuberlin/frontdoor/index/index/docId/4717
URN urn:nbn:de:kobv:83-opus4-47173
[http://nbn-resolving.de/urn:nbn:de:kobv:83-opus4-47173]

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

Acknowledgments

The ninth volume of the Young Cities Research Paper Series "Intelligent Design using Solar-Climatic Vision—Energy and Comfort Improvement in Architecture and Urban Planning using SOLARCHVISION" presents the results gained within the Young Cities Research Project, which was sponsored by the German Federal Ministry of Education and Research (BMBF). We would therefore like to express our sincere thanks to the Federal Ministry of Education and Research for its financial support.

Our thanks are also due to our university, that bears 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 published in this volume was performed at the Chair of Building Technology and Architectural Design (Fachgebiet Gebäudetechnik und Entwerfen). We therefore owe special thanks to Prof. Dipl.-Ing. Claus Steffan, the Chairman of this department, for his scientific support in the field of energy efficiency, as well as his helpful advice on SOLARCHVISION studies within the Young Cities Project. We also would like to express our thanks to the German Academic Exchange Service (DAAD) for its financial support.

Furthermore, we would like to acknowledge Environment Canada (EC) for the access to observed station data, retrieved from the National Climate Data and Information Archive and Iran Meteorological Organization and U.S. Department of Energy for preparing the statistical climate data and weather files.

We are also very grateful for the support received from Dr. Mohammad Yousef Nili, Dr. Mansoureh Tahbaz, Dr. Ali Namazian and Dr. Hadi Nadimi, the professors from the Faculty of Architecture and Urban Planning at Shahid Beheshti University in Tehran, as well as Dr. Robert Off and Dr. Rainer E. Blum from IMS at Anhalt University of Applied Sciences in Dessau for their notable reflection concerning certain aspects within these work processes.

We would also like to thank our colleagues at TU Berlin and at R.M.M. Solarch Studio for their valuable advice, as well as our colleague, Hossein Farahani, for the wonderful photos of Iran's sky, landscape and architecture, which complement this volume.

We are also very grateful to Cornelia Saalmann for her kind cooperation and reliable work in editing this volume. Finally, we would like to thank Sharon Heidenreich for her outstanding proofreading of this volume and büro-d for the precise layout and graphic design.

Guest Prof. Dr. Farshad Nasrollahi
UdK Berlin

MA Arch. Mojtaba Samimi
R.M.M. Studio

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

Thanks to the availability of energy, materials and technologies, the level of comfort in buildings is increasing around the world. However, today we are also facing buildings and cities that are responsible for a high percentage of global energy consumption. Pollution, heat island effect, climate change and global warming are just a few of the challenges that the human race, as well as other living matter on earth, will have to deal with in future. Moreover, as time goes by, we may not necessarily live in healthier conditions with better life styles. Within a limited period, this global and complex situation will need thorough, integrated and local surgery. This book is designed to draw greater attention to the sun and how a solar-climatic vision can influence and improve architectural design and urban planning.

It may not have been discovered yet how small our planet is and how big the effect of a simple decision can be, but it is nevertheless important to be reminded of the sun not only as a powerful and perpetual actor in our dynamic atmosphere but also as a basis for figuring out a variety of adaptive solutions that must be identified and followed. In addition to the changes made by architects, clients and builders as well as planners, municipalities and all other persons who make decisions on plans, the role of those who live inside buildings and cities, not as users, but as producers and maintainers, also bear a certain degree of responsibility. Therefore, the optimization of new constructions, the modification of existing buildings and urban fabric should be considered on a global scale in regard to the sun as well as our future needs. The aim should be to improve energy-efficiency, health, comfort and safety in all living spaces, whether indoors or outdoors. In this respect, the analysis of the current situation, forecasting future scenarios and the development of intelligent alternatives are fundamental steps.

In terms of energy efficiency, daylight provision and internal comfort, the use of advanced building materials and technologies as well as simulation tools can improve the building envelope and its performance. However, it is important to understand when, where and how they should best be applied to achieve an intelligent form as well as a responsive layout with a high level of performance for other essential aspects, too (e.g structure, view, operation). Although today many consider “solar architecture” the attaching of solar thermal collectors and PVs to building roofs and facades, this is only one of the complex tasks which should be integrated in the design. In fact, solar architecture incorporates all the complexities of architecture on different scales. Besides, it has to respond accurately to certain issues resulting from the currently low price of other energy sources in many locations. In addition to the reduction of payments, other valuable improvements associated with solar-climatic considerations in the design should be clarified and compared. During the design process, an optimization (i.e. re-arrangement, re-orientation, re-sizing) of different elements, namely solar surfaces (i.e. transparent/opaque surfaces, shading/reflecting devices, collectors), building volumes and trees, does not necessarily increase the construction costs but can help identify deficient or over-designed elements.

Alongside improving the energy efficiency aspects of individual buildings, a solar-climatic vision in planning can lead to other qualities for the benefit of small and large-scale living spaces, whether indoors or outdoors. Around the world, we must be prepared for more shocking news and annual records if many continue to build buildings, whether cheap or expensive, with little attention to the sun. In neighborhoods on an urban scale, the insufficient analysis and inaccurate decisions regarding building volumes and orientation can affect the potentials and performance of both internal and external spaces in terms of energy production, energy demand, daylight, health, comfort and safety for long periods of time.

This book includes a decade of SOLARCHVISION practices on how architectural design and urban planning can be adapted by the constant path and variable effects of the sun in each location. Sharing such a vision can help architects, urban planners and clients to make more accurate decisions concerning energy and climate-related matters. After presenting fundamental diagrams in different cities around the world (e.g. the sun paths, solar radiation and temperature models), the role of an intelligent design for the building skin is described and analyzed in terms of finding a good relation between outside and inside as well as the direct and indirect collection of solar energy on different building surfaces. This research can bring about new appearances and structures for the creation of smart buildings and responsive cities.

Forewords

"Architecture is the masterly, correct and magnificent play of masses brought together in light" (Le Corbusier, Towards a new Architecture, 1923).

This sounds very poetic, but fact is that the sun has always been a central feature of architectural design and has a significant value in terms of physical aspects. Solar radiation can provide passive heat gain in winter, but also be the cause for overheating in summer. Unfortunately, there are many examples in all climate zones which show that architects have ignored the impact of the sun in their designs. The results are uncomfortable conditions indoors and a high consumption of energy.

Solar geometry and radiation differ according to climate zone and season. These considerations have to be taken into account in the decision-making process of, for example, orientation, building materials, glazing ratio, shading devices and, not to be forgotten, all issues in regard of the local climate. Today digital simulation tools are available to evaluate and optimize architectural designs throughout the planning process.

In this book, Mojtaba Samimi and Farshad Nasrollahi demonstrate how solar features can be incorporated effectively in the design of buildings in different climate zones. SOLARCHVISION, a very powerful simulation tool, is used to analyze the influence of the sun for particular sites and climates. The results clearly show how the method can be applied by architects and planners in the design process of not only buildings but also urban designs with the aim of optimizing orientation, the micro-climate and the choice of typology. Illustrations and graphs highlight the interdependencies of sun, geometry and building. This book is an indispensable manual for all architects and urban planners involved in the design of residential and non-residential buildings.

Prof. Claus Steffan
TU Berlin

gebäudetechnik
und entwerfen
gte

Technische Universität Berlin
Building Technology and Architectural Design

The main objective of a building design is not to save energy. At first, the building should be designed for its users and the purpose of meeting their needs. In the design process, the architect is responsible for defining the shape and orientation of the building, the size and position of transparent areas in the facade and the selection of materials for the construction. In other words, the architect uses the design to determine the energy balance, the indoor climate and the heating and cooling demand of the building in relation to the local climate.

The book at hand, written by Mojtaba Samimi and Farshad Nasrollahi, helps architects to become more aware of these crucial factors, which are dependent on the thermal behavior of the building envelope. A general analysis demonstrates how to best approach the design process with regard to the local climate conditions - so by taking into consideration, and not excluding, solar radiation and temperature. The SOLARCHVISION tool has been developed for this purpose, namely to study the patterns of climate parameters, such as direct beam radiation, sun paths, air temperature, wind speeds and directions, and assess the impact the data has on the building envelope and the architectural design in general.

The authors illustrate the "positive and negative effects of solar radiation" for several basic building shapes, but also some more complex case studies, dependent on the climate of the particular location. Detailed analyses are described for hot, intermediate and cold climate regions (Europe, U.S., Canada, Australia, East Asia, Iran). The SOLARCHVISION approach is not restricted to single buildings but is also used to discuss the interrelations between buildings and their neighborhood on a district level. The book concludes with an application of the generated approach in the newly planned city district, Shahre Javan Community, which was developed within the German-Iranian research project "Young Cities—Developing Energy-Efficient Urban Fabric in the Tehran-Karaj Region".

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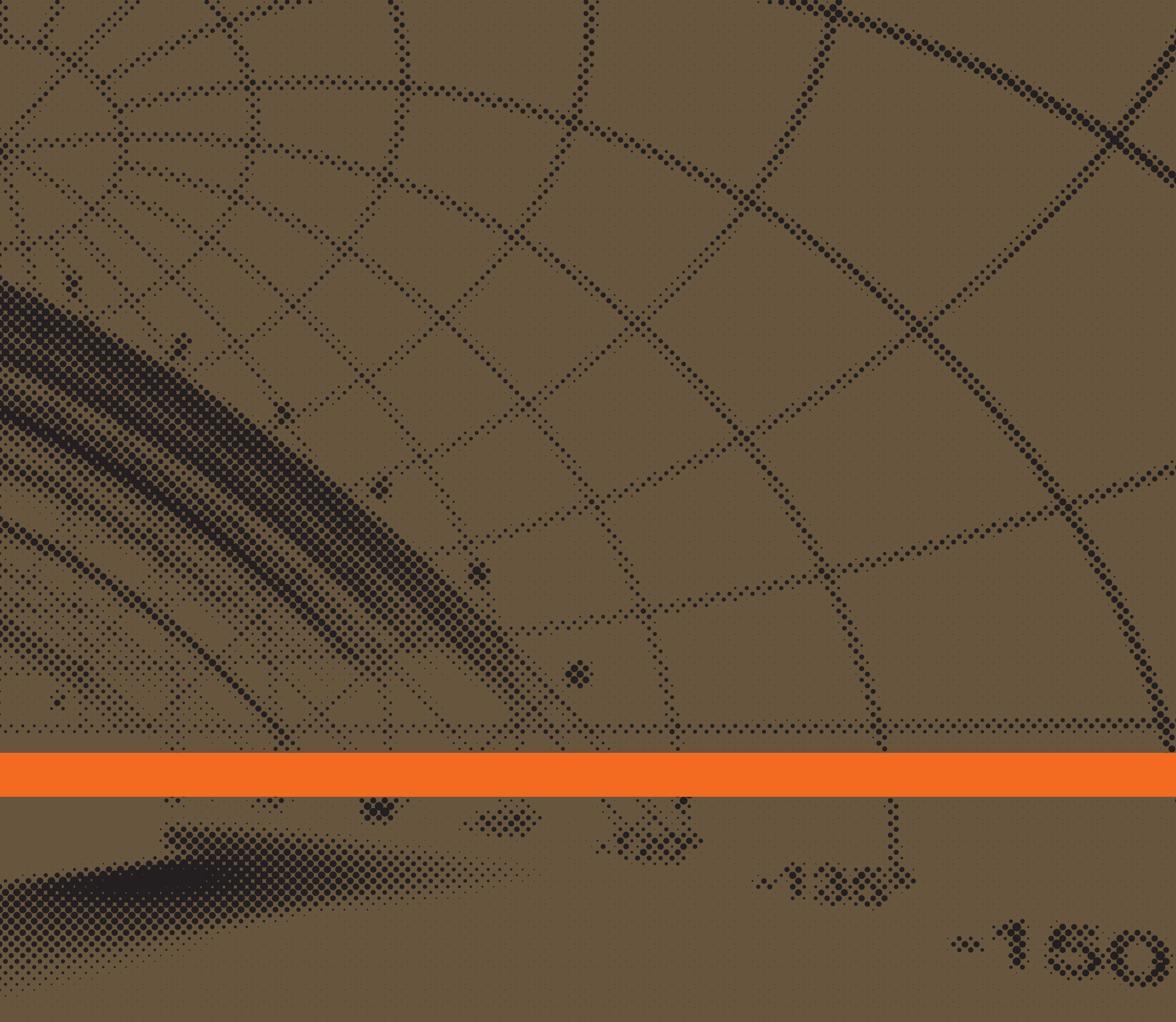
Building Services Engineering (VPT)

I
The Sun around the World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One of the main goals of planning cities and buildings is to provide health, comfort and safety for people. In this respect, the role of the city and buildings' response to the climate is essential. Considering the variable effects of the sun in each location, basic and applied research is needed to help architects, urban planners and clients to make a more accurate decision concerning energy and climate-related features.

Regarding the global and local objectives of a sustainable design, this book is designed to highlight one of the greatest challenges that architects and urban planners face today: the challenge of how to develop and improve the quality of both internal and external living conditions by means of a solar-climatic vision in an integrated design approach.

After an introduction to the subject of sun path diagrams as well as radiation and climate patterns in different cities around the world, the SOLARCHVISION method of optimization is described for both active and passive strategies. Finally, the impact of the sun on buildings and urban townscapes is analyzed to demonstrate the remarkable role of different building geometries as well as their interaction in terms of orientation for creating a climate-suitable response in indoor and outdoor living spaces.

Thus, this study shows how throughout all stages of the design, a solar-climatic vision can guide urban planners, architects and landscape architects towards developing not only more energy-efficient buildings but also healthier and more comfortable living spaces for the future. As we will see in many cases, the strategy is to identify design solutions which cost no more and only involve considering the sun in planning.

1 The Earth around the Sun

The earth's sphere, with a radius of about 6,370 km, orbits around the sun's sphere, with a radius of 700,000 km, which is 110 times bigger than the earth's radius, on a large circle, with an approximate radius of 149,000,000 km, which is 214 times bigger than the sun's radius, at a speed of 30 km/s (108,000 km/h). This is so fast that the earth passes the distance of its radius 17 times each hour as well as more than 6.5 times the distance to the moon in 24 hours!

On this orbit, the distance between the earth and the sun changes between approximate values of 147,000,000 km and 152,000,000 km; it is for this reason that the path the earth takes around the sun is considered an ellipse with the sun located at the center, which is in actual fact completely wrong.

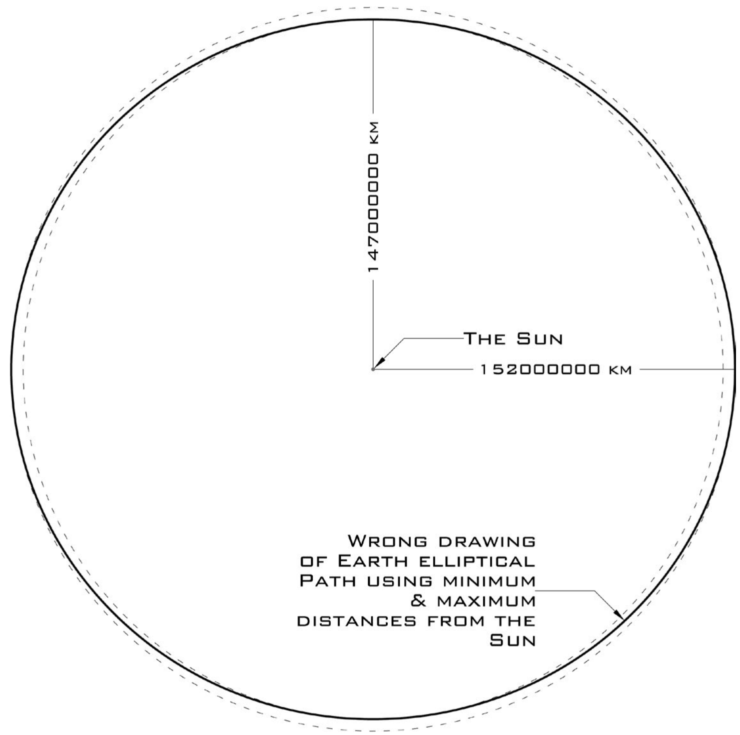


Fig. 1: Wrong presumptions concerning the earth's elliptical orbit path around the sun

Theoretically, the orbit path of the earth around the sun has an elliptical shape, but attention has to be paid to the fact that it is actually very close to a circle since the relation between the short and long diagonal is 0.999! The reason for the changes in the distance between the sun and the earth is that the sun is not located exactly at the center.

One remarkable phenomenon resulting from the fact that the sun is not at the center of the orbit path is the change of speed in the earth's or-

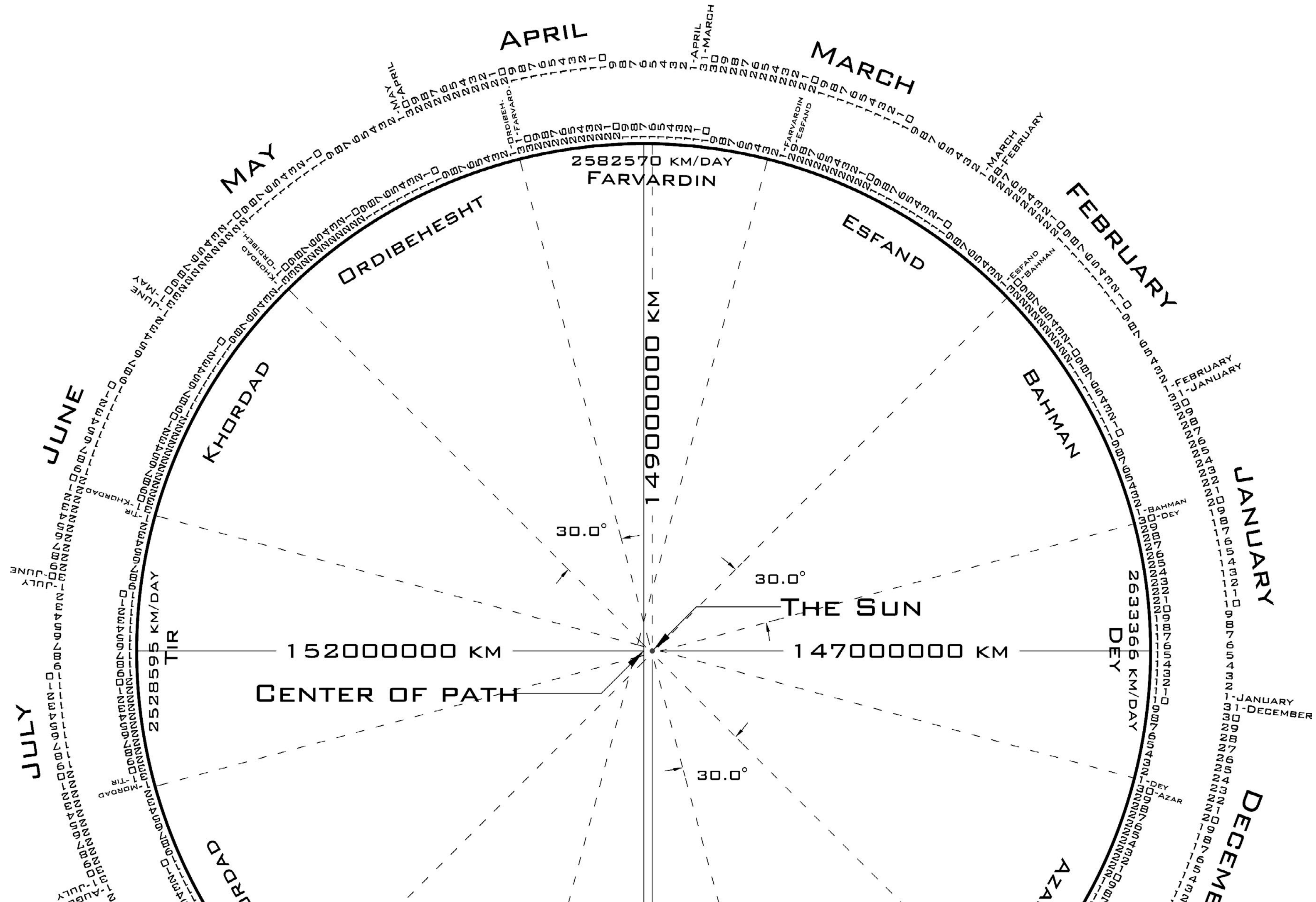


Fig. 2: Accurate drawing of the earth's orbit path according to the Persian calendar

bit at different places along the path, which can be defined by Kepler's second law. So when the earth reaches its closest distance to the sun on the first days of January, it reaches its highest speed; on the other hand, it reaches its lowest speed during the first days of July when its distance to the sun is at its maximum. This is the reason for the changes in the number of days in different months of the year, which is best reflected in the Persian calendar where the months during the warmer part of the year have 31 days instead of those with 30 days during the colder periods.

Another remarkable phenomenon resulting from the sun not being at the center of the orbit path is the change in solar radiation, which reaches the earth from different positions along the path, differences of about ±3.34 percent.

As a result, the model of the earth's orbit around the sun can be simplified as illustrated in Figure 3, where the earth rotates 30 degrees each month on a circle. In this case, the sun is considered to be at the center; nevertheless, it is necessary to apply a ±3.34 percent change to the radiation model throughout the annual cycle.

Solar constant and its relation to the distance between the earth and the sun:

$$I = I_0 \times [1 + 0.0334 \times \sin(Date\_Angle)]$$

"Outside the earth's atmosphere, the solar radiation intensity (I_0) is 1,367 W/m²" (METEONORM Theory Part, 2003)

On the earth's orbit around the sun, which is called a year, the earth rotates around its north-south axis, which is responsible for creating the phenomenon of day, night, sunrise, noon and sunset. This rotational movement as well as the spherical shape of earth generates the different geographical regions, between the equator and each pole owing to the differences in the amount of solar radiation received on the different sloped surfaces of the earth.

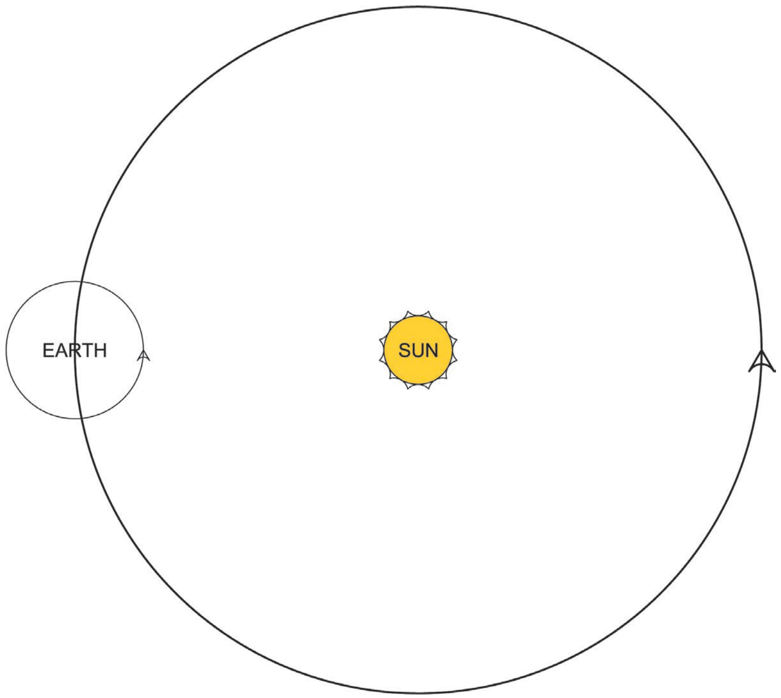


Fig. 3: Simplified model of the earth's orbit path around the sun

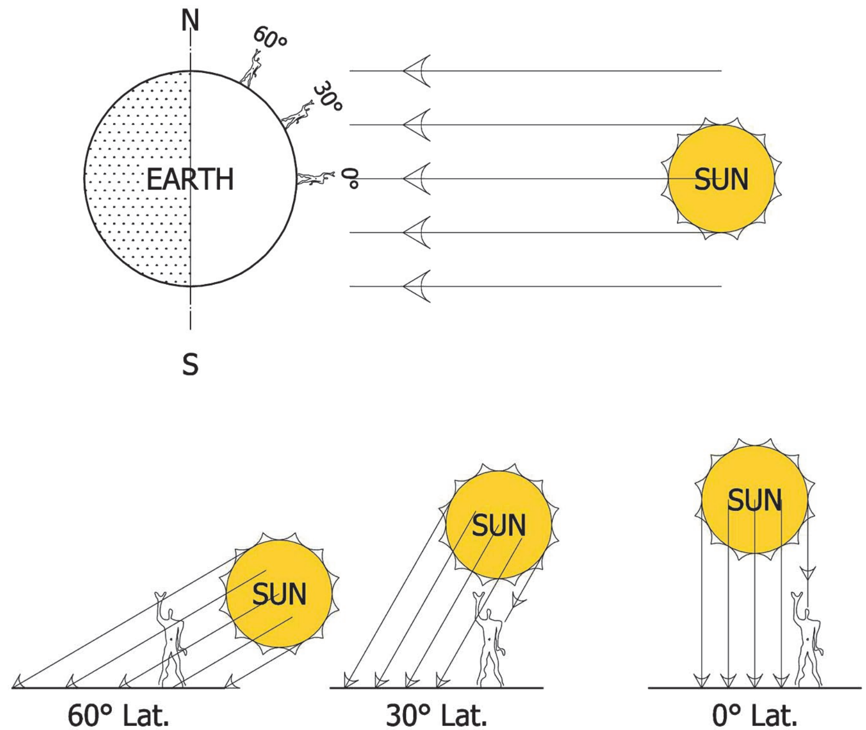


Fig. 4: Differences in the amount of solar radiation received on the earth's different sloped surfaces

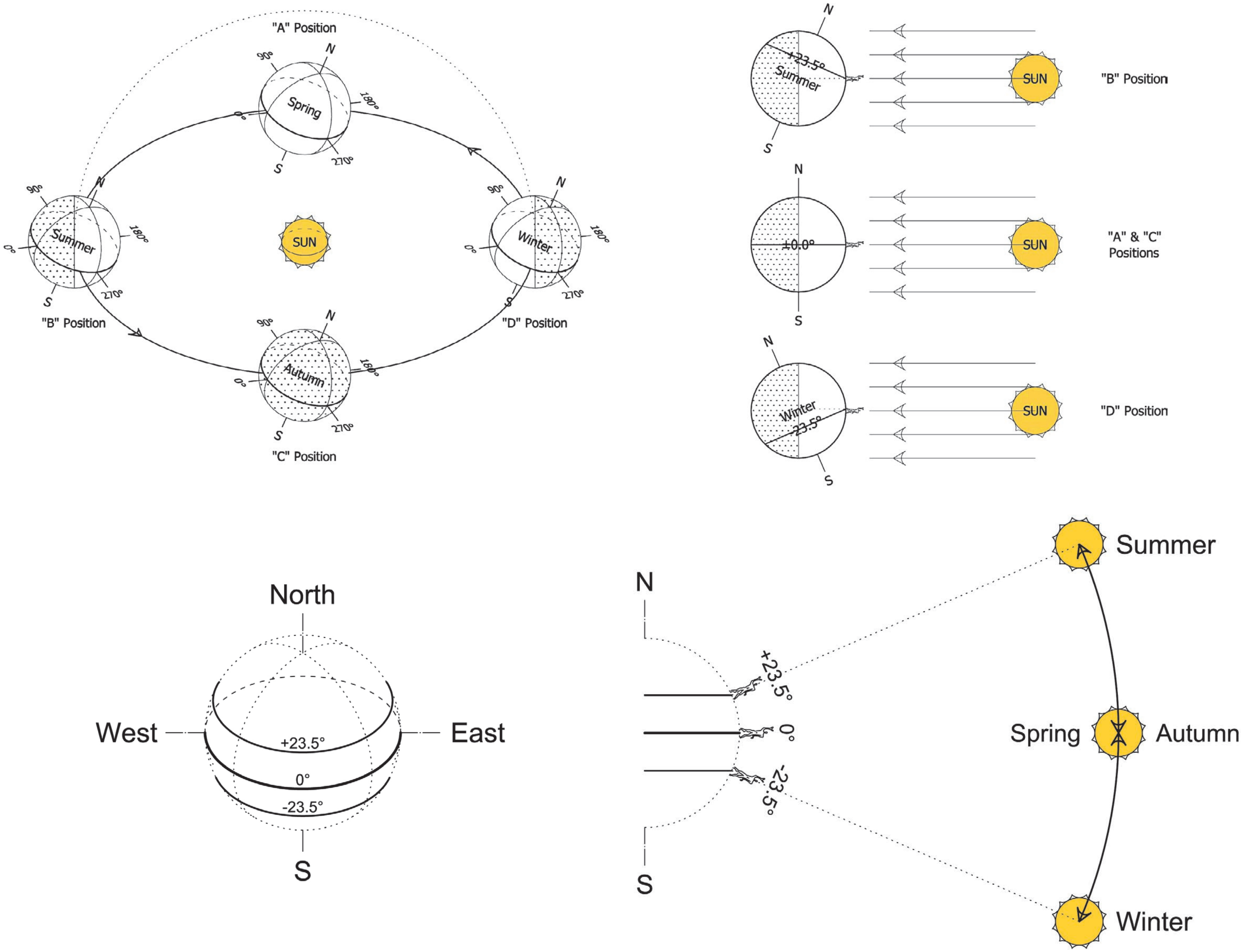


Fig. 5: Different situations of the earth during its orbit around the sun

Contrary to public belief, that the different distances between the earth and the sun are responsible for the seasons on earth, these differences are not only ineffective but also have a controversial effect when the earth reaches its closest distance to the sun in January and its maximum distance in July.

Regarding the earth's orbit around the sun, the most remarkable aspect is the 23.45° angle between the north-south axis of the earth and the plane of the annual orbit.

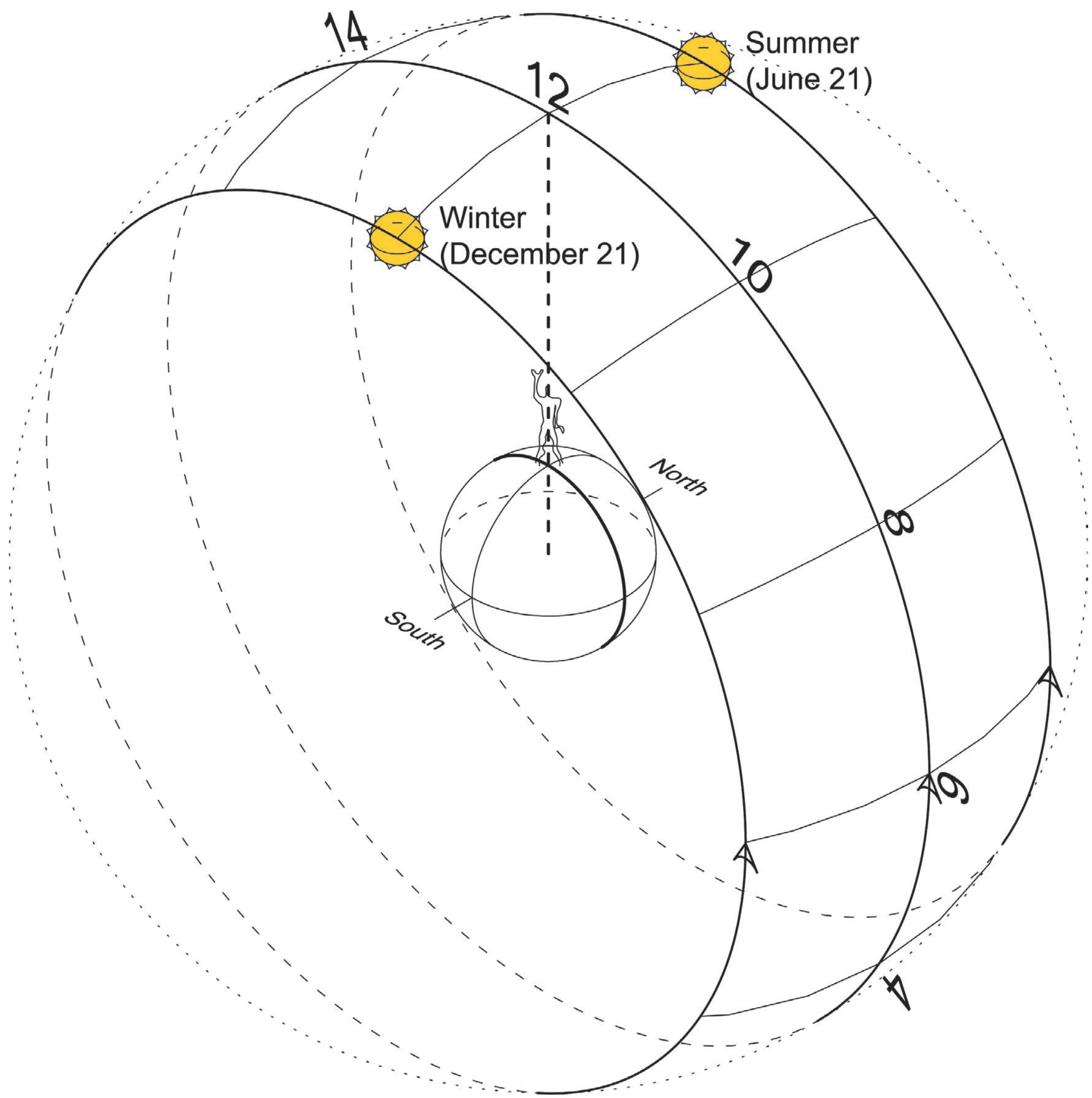


Fig. 6: Movement of the sun around the earth

2 View from the Earth's Perspective

If the earth is considered the static center of the universe, it appears as if the sun rotates once a day. In this case, it is necessary to be aware of its pendulum movement throughout the year as it reaches its closest point to the South Pole on 21 December and its closest point to the North Pole on 21 June.

As the different views of the sun's path for the latitude of 0° illustrate, the movement of the sun in the sky at the equator and the areas close by (for instance between 20° N and 20° S) is fairly simple in terms of geometry. At a latitude of 0°, the sun rises at 6.00 a.m. in the morning and sets at 6.00 p.m. in the afternoon. The length of day and night, therefore, remains at 12 hours throughout the year. To better understand the path of the sun in the sky at each location, one should first study its path on 21

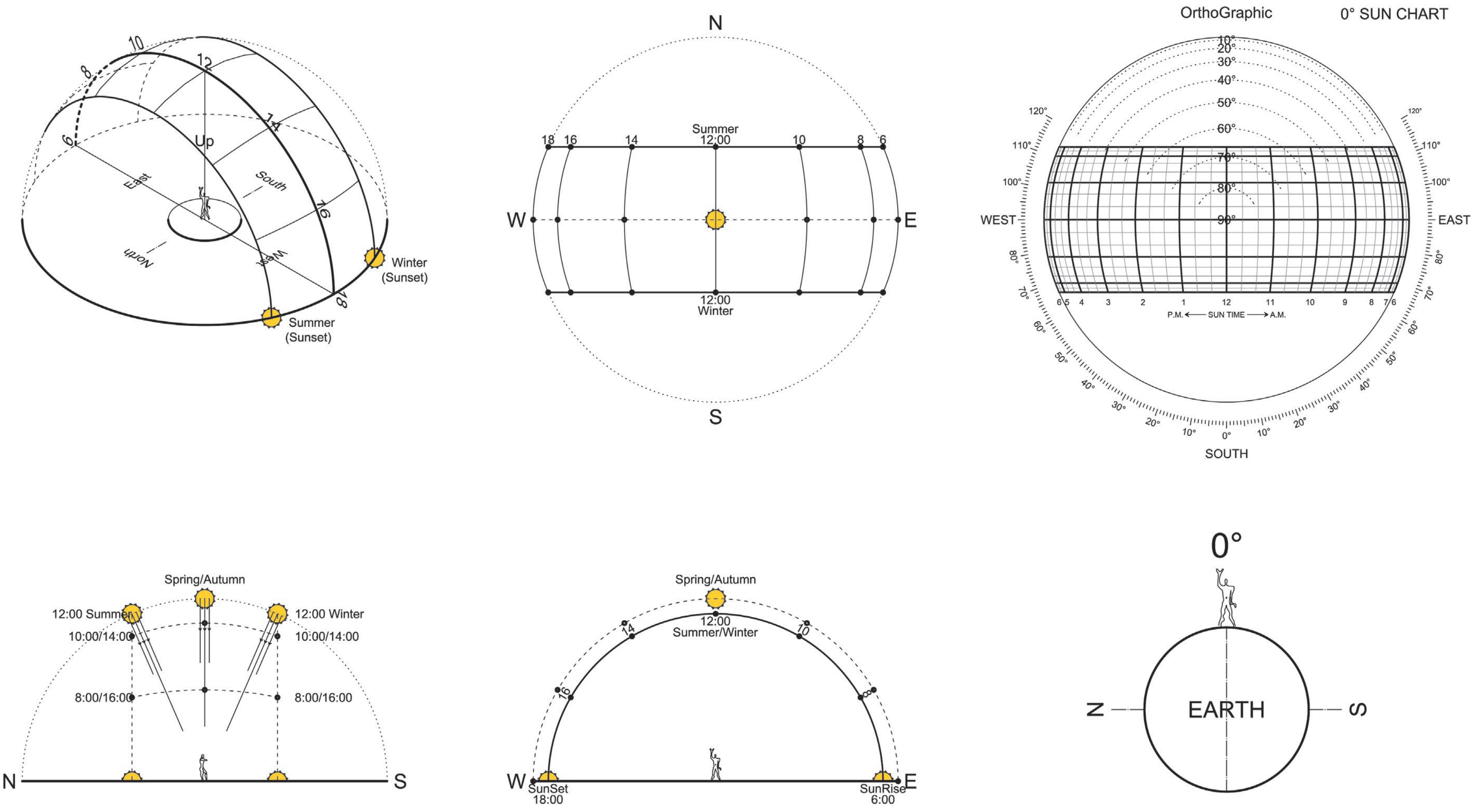


Fig. 7: Top, front, left and isometric views of the sun's movement in the sky on the earth's surface, latitude = 0° N

March and 22 September, which we consider as the start of spring and autumn in the northern hemisphere. As everybody knows the sun rises in the east and sets in the west, and reaches its highest daily altitude at noon. As a result of the 0° latitude, the sun's path on 21 March and 22 September starts at 6.00 a.m. from true east; it reaches the altitude of 90° at noon and finally sets at true west at 6.00 p.m. On the other hand, on other days of the year, the azimuth of the starting and ending position of the sun at sunrise and sunset, as well as the highest altitude at noon, changes in relation to the date. On 21 June, for instance, which is the beginning of summer in the northern hemisphere, at a latitude of 0°, sunset, noon and sunrise all occur at similar times to what is mentioned above but with a slight shift of the sun's starting, middle and end point on the circular path to the north.

At a higher latitude of, for instance, 60° N, which is presented here, the sun's path in the sky should first be studied on 21 March and 22 September when the positions of sunrise and sunset are true east and west, and the middle point at noon could simply be described by the latitude of the between summer and winter. Consequently, for instance at 60° N and on 21 June, the sun rises in the N.E. at about 3.00 a.m., reaches the altitude of 53.5° (90° + 23.5° — Latitude) at noon in the south and finally sets in the N.W. at around 9.00 p.m. Therefore, a location at a higher latitude has

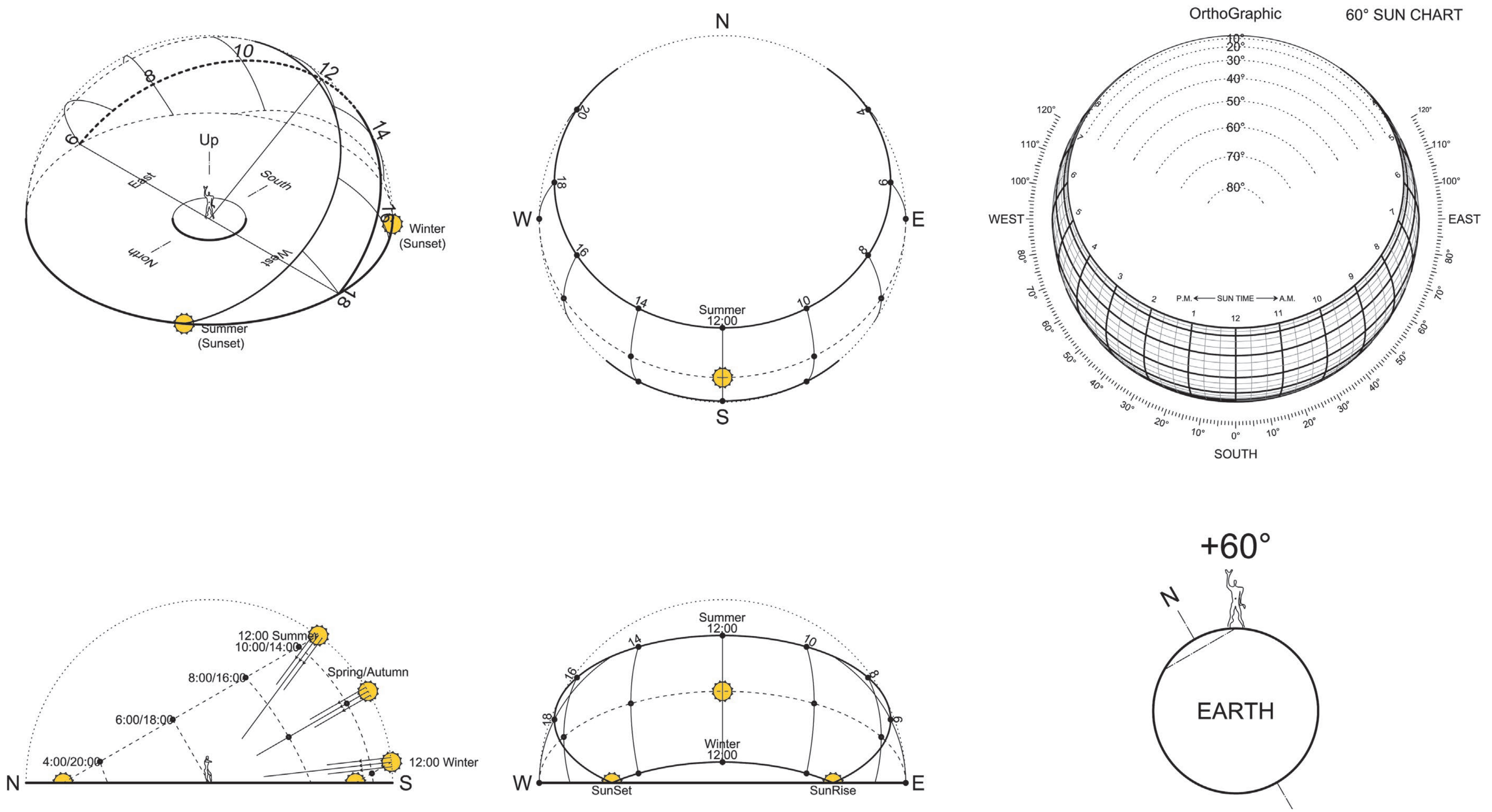


Fig. 8: Top, front, left and isometric views of the sun's movement in the sky on the earth's surface, latitude = 60° N

location. Similar to what is described for the latitude of 0° N and, as a general rule everywhere on earth, on 21 March and 22 September the sun's path starts at 6.00 a.m. at true east, it reaches the altitude appropriate to the latitude (90° — latitude of the location) at noon and finally sets at true west at 6.00 p.m. On the other hand, on other days of the year, a slight change in the position of the section plane, where the sun path is located (see left view), produces a significant change, namely in the daytime more sunny hours in summer, in comparison to a location at the equator. In winter, the situation at a latitude of 60° N is the complete reverse as the sun rises after 9.00 a.m. in the S.E., reaches a low altitude of 6.5° (90° – 23.5° — Latitude) at noon and sets before 3.00 p.m. in the S.W.

A study of the sun's path for a 30° N latitude illustrates the similarities and differences to the 0 and 60° N latitudes. Again, on 21 March and 22 September the sun‘s path starts at 6.00 p.m. at true east, it reaches the

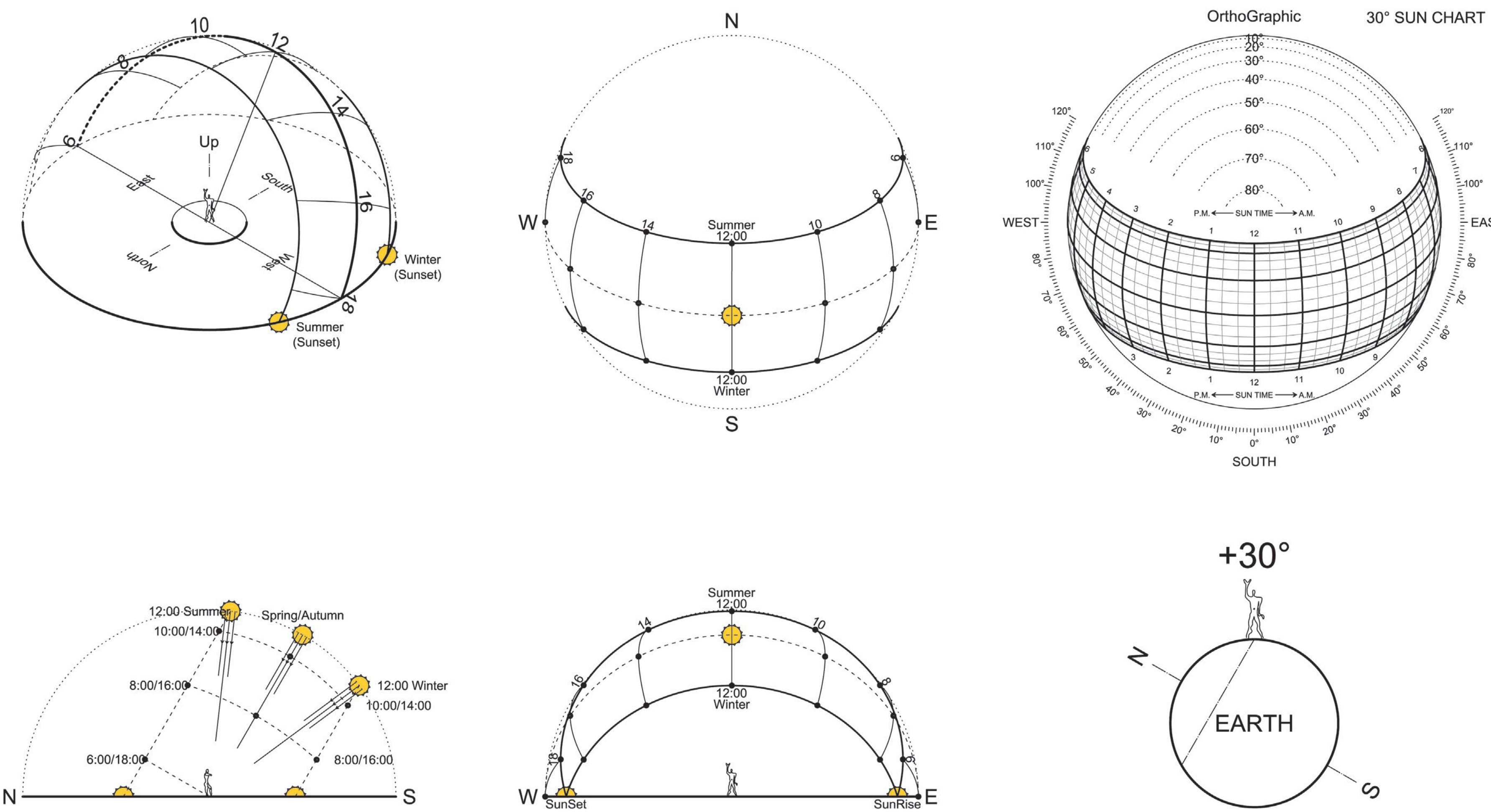


Fig. 9: Top, front, left and isometric views of the sun's movement in the sky on the earth's surface, latitude = 30°N

altitude equal to 30° (complementary angle of the latitude) at noon and finally sets at true west at 6.00 p.m. In winter, it rises around 7.00 a.m. somewhere between east and S.E., reaches the altitude of 36.5° (90° – 23.5° — Latitude) at noon and finally sets at around 5.00 p.m. somewhere between S.W. and west. On the other hand, in summer it rises around 5.00 a.m. somewhere between east and N.E., reaches the altitude of 83.5° (90° + 23.5° — Latitude) at noon and finally sets at around 7.00 p.m. somewhere between N.W. and west. In fact, understanding the position of the sun in the sky in each location and the ability of drawing proper sketches can help architects as well as solar engineers to consider the sun in their design. This is in actual fact the purpose of these drawings.

On the other hand, the exact position of the sun at each moment can be calculated by mathematical formulas or computer programs. The position of the sun in the sky is generally described by two factors: the azimuth angle and the altitude angle. Depending on the latitude, different points on earth have different sun paths. The traditional formulas of azimuth and altitude can produce a number of faults in scripting computer programs. Range checking statements, such as “if” and “else” statements, are therefore necessary everywhere in the functions. For example, at the equator and all areas between the latitudes 23.5° N and 23.5° S, the sun can reach a position at exactly the highest point in the sky on two days of the year at noon. Although the altitude of this position can be defined as a value of 90°, the azimuth is undefined, which leads to a “division by zero” error in the script if it is not controlled appropriately. To avoid these problems, the SOLARCHVISION computer program uses the original algorithm to calculate the position of the sun in the sky by means of a 3-dimentional vector matrix as was published in “A New Approach For Solar Analysis of Buildings — WORLDCOMP 2008”.

```
function SunPosition StationLatitude DATE_angle HOUR = {
    DEC = 23.45 × sin(DATE_angle - 180.0)
    a = sin(DEC)
    b = cos(DEC) × -cos(15.0 × HOUR)
    x = cos(DEC) × sin(15.0 × HOUR)
    y = -(a × cos(StationLatitude) + b × sin(StationLatitude))
    z = -a × sin(StationLatitude) + b × cos(StationLatitude)
    return [x, y, z]
}
```

Having calculated this vector, it is always easy to find and plot the azimuth and altitude of the sun during day and night for all locations.

X_equidistant = acos(z) × sin(atan2 x y)
Y_equidistant = acos(z) × cos(atan2 x y)

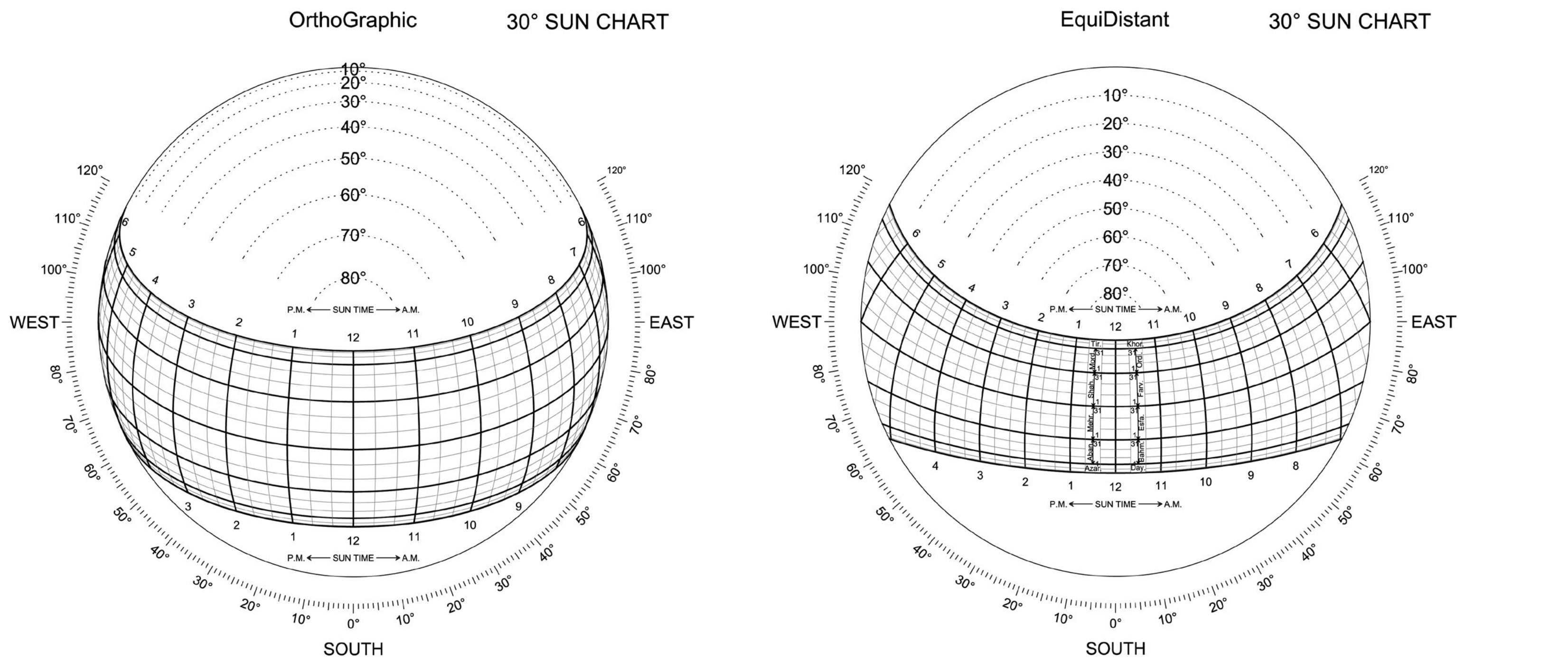
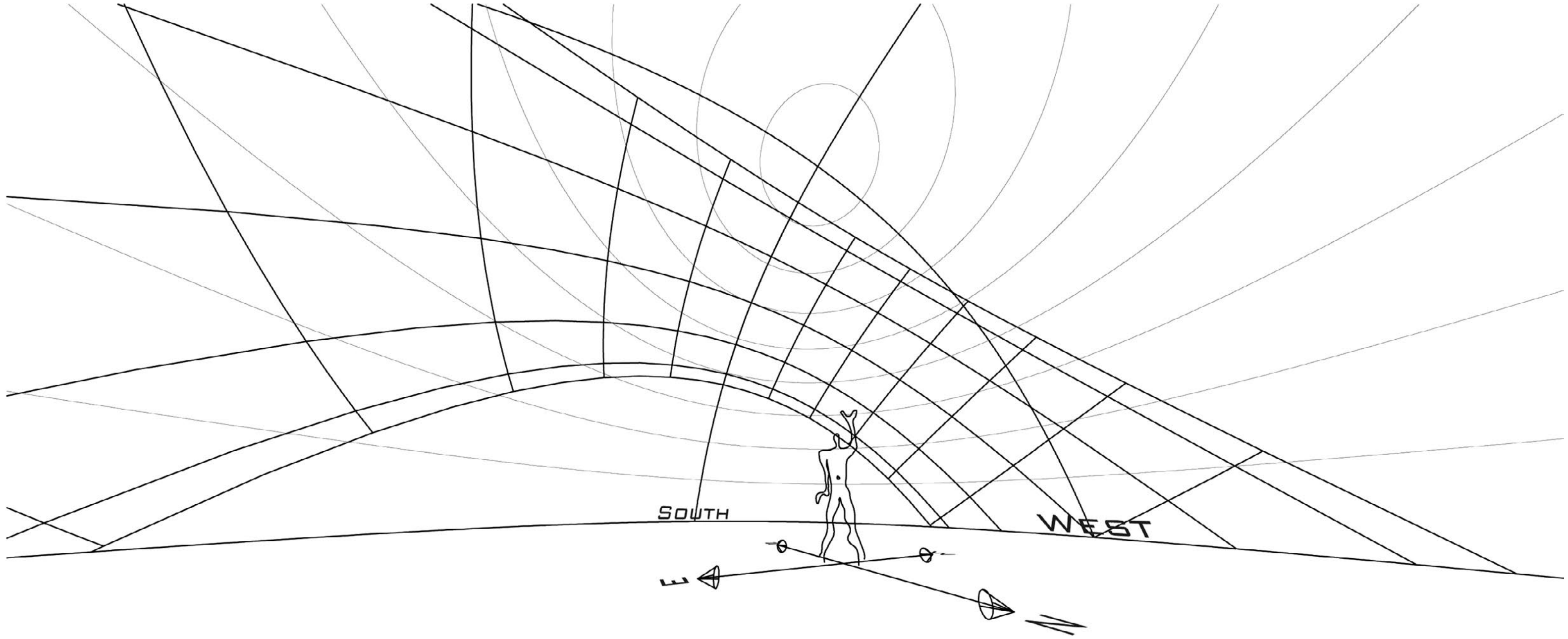


Fig. 10–11: Differences between orthographic and equidistant sun path diagrams

Figure 11 shows the equidistant sun path diagram for the latitude of 30° N in which the same distances between different altitudes are plotted with equal measurements unlike the orthographic method. As a result, the altitude of the sun can be identified more easily and measured from an equidistant diagram. Moreover, the sun path diagram can simply be extended to negative altitudes so that the night-time azimuth and altitude of the sun can be also plotted (Figure 13).



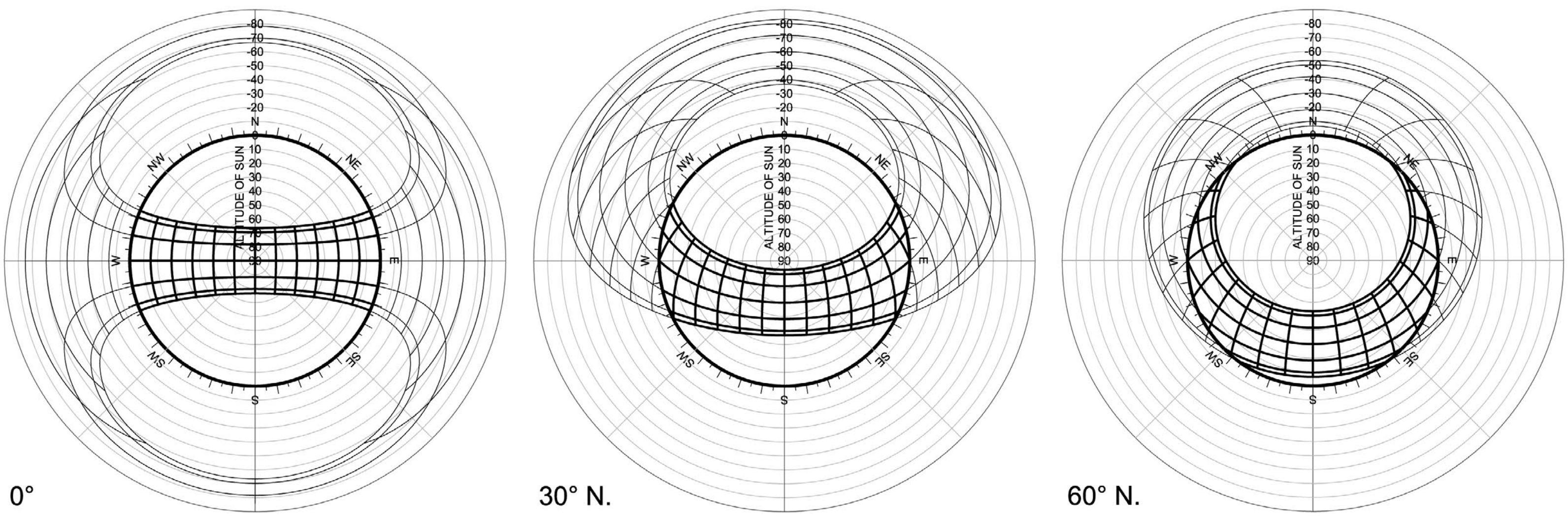


Fig. 12: Perspective view of the movements of the sun in the sky on the earth's surface, latitude = 30°N
Fig. 13: 24-hour equidistant sun path diagrams for different latitudes in the northern hemisphere

It is also necessary to mention that there are other correction factors in this field, which are not presented here in order to simplify further models for general readers. For instance, slight changes in noon time occurring during the year are not discussed; meanwhile, noon always presents a solar noon time, in which the sun reaches its highest daily altitude and its azimuth is on the north-south axis.

Fig. 14: Paths of stars in the sky during the night, location: earthquake stricken village of Esfahak near Tabass, Iran (Hossein Farahani)

The photo above, which was taken during the night, illustrates the movement of the stars around the earth. The movement is the result of the earth's rotation around its own axis over time. Because the position of the North Star does not change for each location over time, the angle between the horizon line and the plane, in which each of these paths are located, expresses the latitude of the location on earth.

Fig. 15: Sun, atmosphere and earth, location: Lut desert, Iran (Hossein Farahani)

The amount of incoming solar radiation that reaches a plane perpendicular to the rays of the sun on the outer surface of the earth's atmosphere is called solar constant. It changes marginally over time according to the sun's changes as well as the changes in the distance between the earth and the sun during the year.

The amount of radiation received on the surface of the earth in each location consists of different values of direct, diffuse and ground-reflected radiation. The radiation changes according to not only statistical geographic parameters, such as latitude and elevation, but also dynamic weather conditions that vary significantly over time in each location. Therefore, in a clear, cloudless sky, the amount of direct beam radiation can reach high values of 1,000 W/m² and more in one location. Moreover, in an open area, in a desert or even in a snow-covered area, the reflection from the surrounding landscape can increase the amount of radiation that reaches a surface at a certain time significantly, reaching values near or higher than the solar constant. On the other hand, if direct radiation declines, the amount of diffuse radiation either decreases or increases depending on the situation of clouds, humidity and particles in the air, such as dust, pollution, etc.

Figure 16 illustrates the plot of hourly direct beam radiation on each day during different months of the Typical Meteorological Year (TMY) for the city of Tehran. The diagram shows that the low altitude of the sun after sunrise and before sunset (below 15°) can decrease the amount of direct beam radiation significantly. On the other hand, around noon, direct beam radiation reaches its maximum point on sunny days. It is worth noting that on sunny days in winter (for example February), the amount of direct beam radiation can reach high values of over 800 W/m² for several hours.

The diagram also demonstrates how variable the sun is in each location over time. The pattern plotted for a single year is never the same

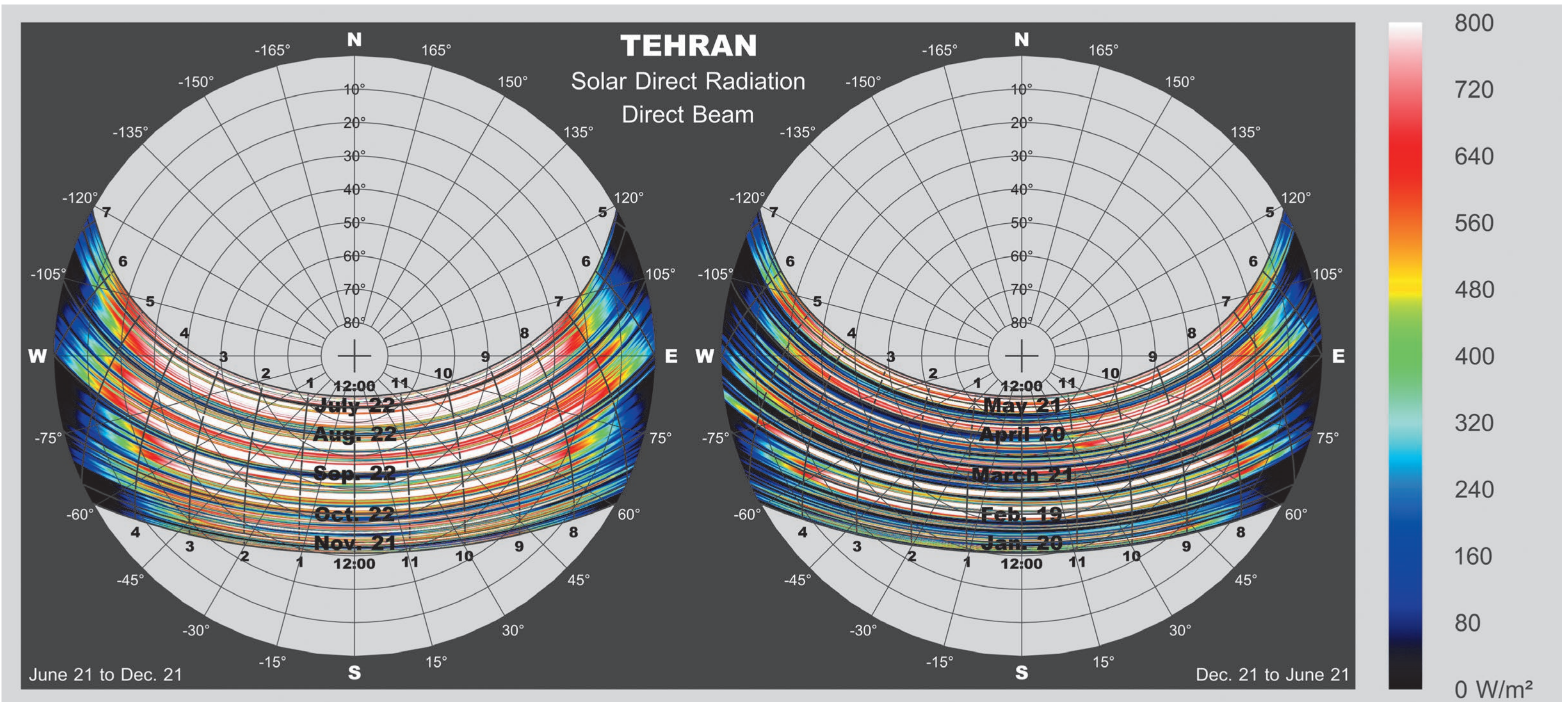


Fig. 16: SOLARCHVISION plot of hourly direct beam radiation data of Tehran (Meteonorm 6.0 TMY file for Tehran)

again in another year. Therefore, it is always difficult to reach a general pattern of direct solar radiation for each location; nevertheless, the average patterns can be useful to illustrate the main characteristics of direct beam radiation in a certain location and standardized for a different period of time (e.g. 30-day average in one year or an average over several years for each day of the year).

As a few cloudy days in a sunny month or a few sunny days in a cloudy month affect the average values of direct beam radiation considerably, the monthly average values of direct beam radiation are not the best parameters to present the general characteristics of a certain location. To achieve better standardized monthly models of solar radiation, a specific algorithm was developed during the research of the “SOLARCHVISION studies on Young Cities Project” in 2011. According to this method, the standard values to present an average pattern of each month are calculated by assigning different linear weights to each data point according to the difference between their sorted order and median value within that month. In this way the average result is affected not only by the median amount and its surrounding neighbors but also by all other amounts.

$$f(i) = \frac{n+1}{2} - \left| \frac{n+1}{2} - i \right|$$

$$\tilde{a} = \frac{\sum_{i=1}^{n} f(i) \times a_i}{\sum_{i=1}^{n} f(i)}$$

$$\bar{a} = \frac{\sum_{i=1}^{n} 1 \times a}{\sum_{i=1}^{n} 1}$$

As the first example considers the five values 100, 750, 900, 950 and 1,000 W/m² as the direct beam radiation at noon on five consecutive days, the mean value for these amounts is 740 W/m², which is lower than four out of five amounts. On the other hand, the SOLARCHVISION standard method calculates the value of 800 W/m² as the average, which is 60 W/m² higher than the mean value and indicates a greater probability for a sunny situation during that period.

$$\tilde{a} = \frac{1 \times 100 + 2 \times 750 + 3 \times 900 + 2 \times 950 + 1 \times 1000}{1 + 2 + 3 + 2 + 1} = 800$$

$$\bar{a} = \frac{1 \times 100 + 1 \times 750 + 1 \times 900 + 1 \times 950 + 1 \times 1000}{1 + 1 + 1 + 1 + 1} = 740$$

The second example concerns the series 100, 150, 200, 350 and 1,000 W/m². The mean value for these amounts is 360 W/m², which is higher than four out of five amounts. The SOLARCHVISION standard method, on the other hand, calculates the value of 300 W/m² as the average which is 60 W/m² lower than the mean value and indicates a greater probability for a cloudy situation during that period.

$$\tilde{a} = \frac{1 \times 100 + 2 \times 150 + 3 \times 200 + 2 \times 350 + 1 \times 1000}{1 + 2 + 3 + 2 + 1} = 300$$

$$\bar{a} = \frac{1 \times 100 + 1 \times 150 + 1 \times 200 + 1 \times 350 + 1 \times 1000}{1 + 1 + 1 + 1 + 1} = 360$$

The graphs presented in the appendix also illustrate that this method can be used successfully to find an average pattern of other climatic parameters. However, unlike the direct beam radiation and the wind speed, the difference between the averages resulting from this method and the classical average (mean) is not quite so remarkable for the case of Tehran.

Figure 17 presents the monthly average values of hourly direct beam solar radiation resulting from the SOLARCHVISION standard method during a Typical Meteorological Year (TMY) for the city of Tehran.

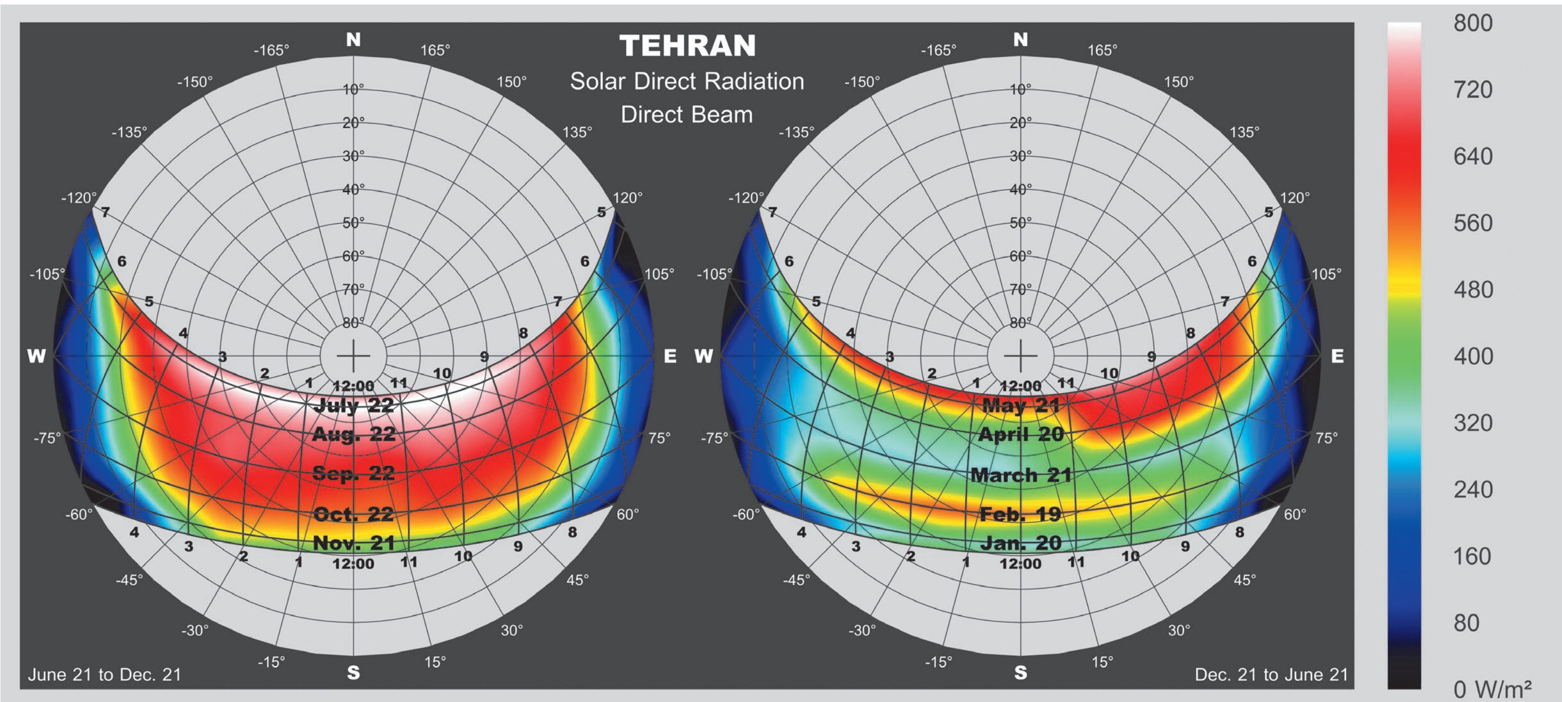
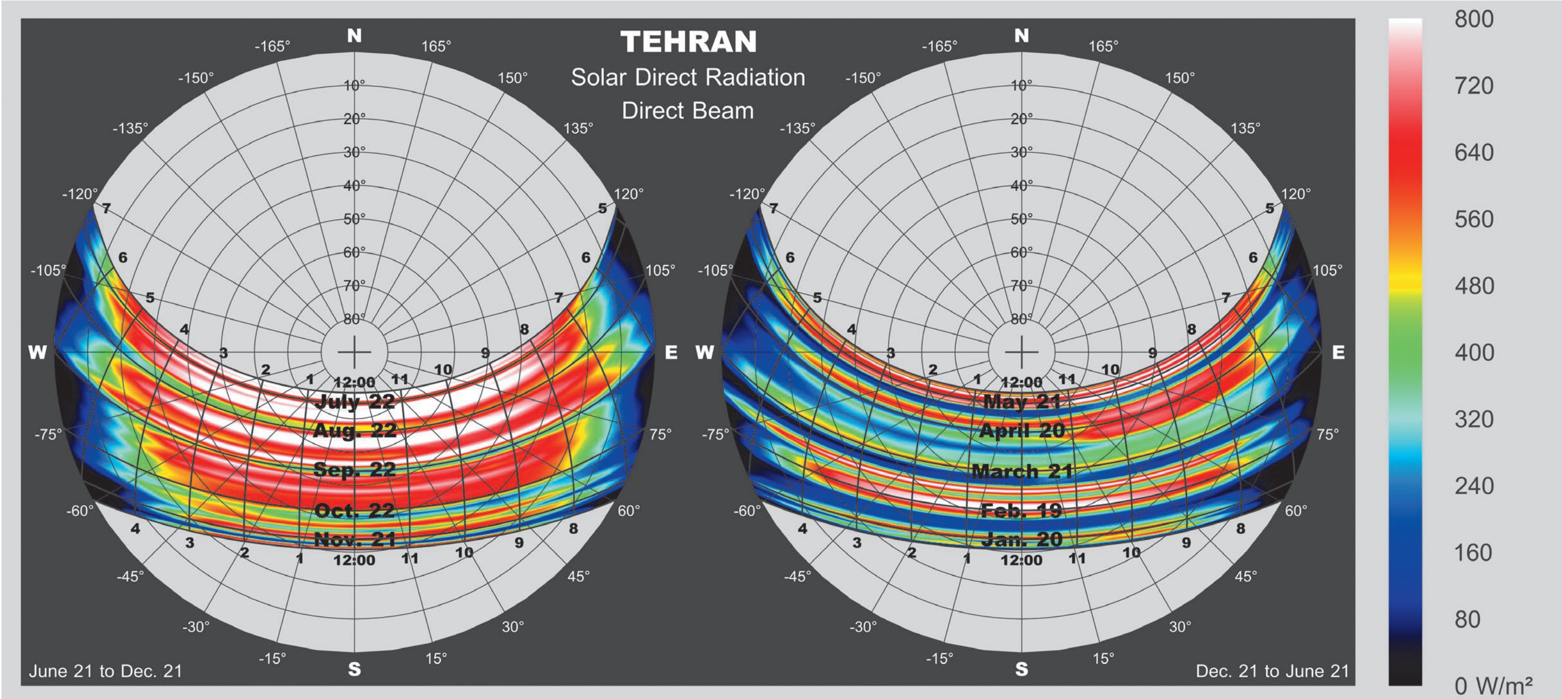


Fig. 17: SOLARCHVISION plot for 30-day average of direct beam radiation data for Tehran (Meteonorm 6.0 TMY file for Tehran)



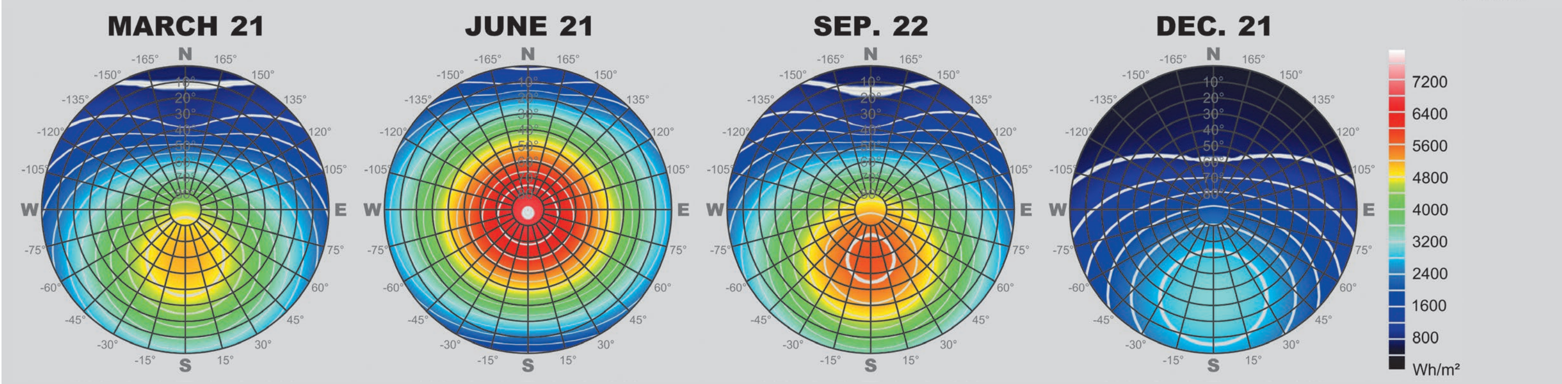
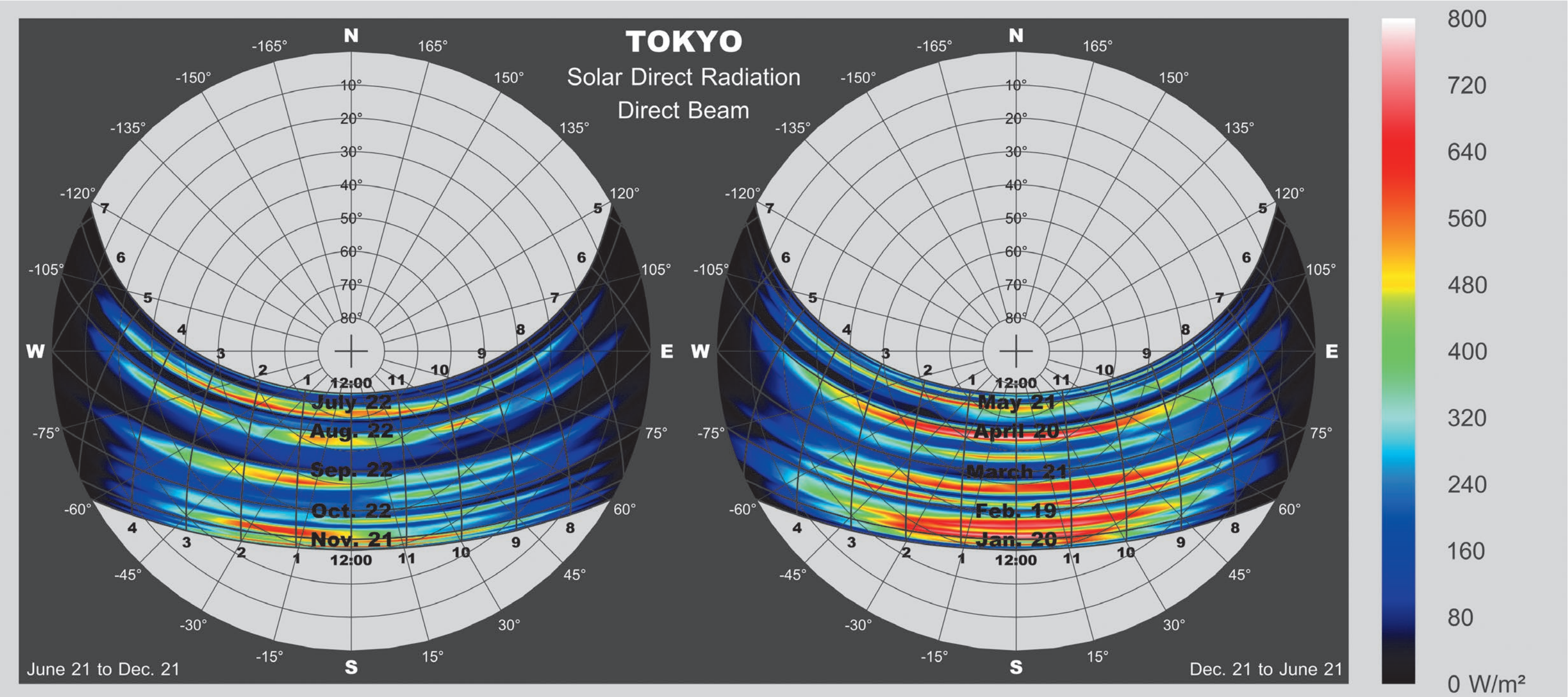


Fig. 18: SOLARCHVISION plot for 5-day average of direct beam radiation data for Tehran (Meteonorm 6.0 TMY file for Tehran)
Fig. 19: Total daily radiation during the year for different surface orientations and inclinations in Tehran

Regarding the generally sunny situation between June and November in Tehran, the left side of the diagram shows that the amount of direct beam radiation is mainly subject to the change of the sun's altitude in the sky. On the other hand, as the right side of the diagram illustrates, the weather conditions on cloudy days between April and December are further factors affecting the amount of direct beam radiation in addition to the sun's altitude at each hour.

As the previous diagrams demonstrate, both the daily and monthly plots of hourly direct radiation are useful to illustrate the different daily and monthly characteristics of the sun in a certain location. A standardization with fewer days (e.g. every 5 days) can highlight the changes in the days of each month and year more precisely. For instance, Figure 18, which illustrates a 5-day average of hourly direct beam radiation during a Typical Meteorological Year (TMY) for the city of Tehran, clearly shows



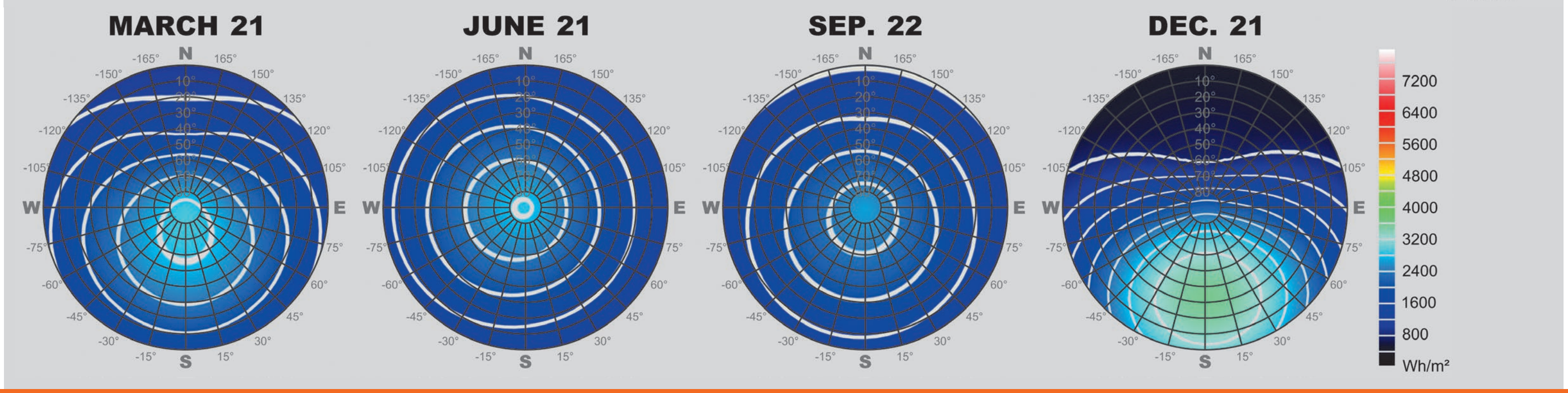
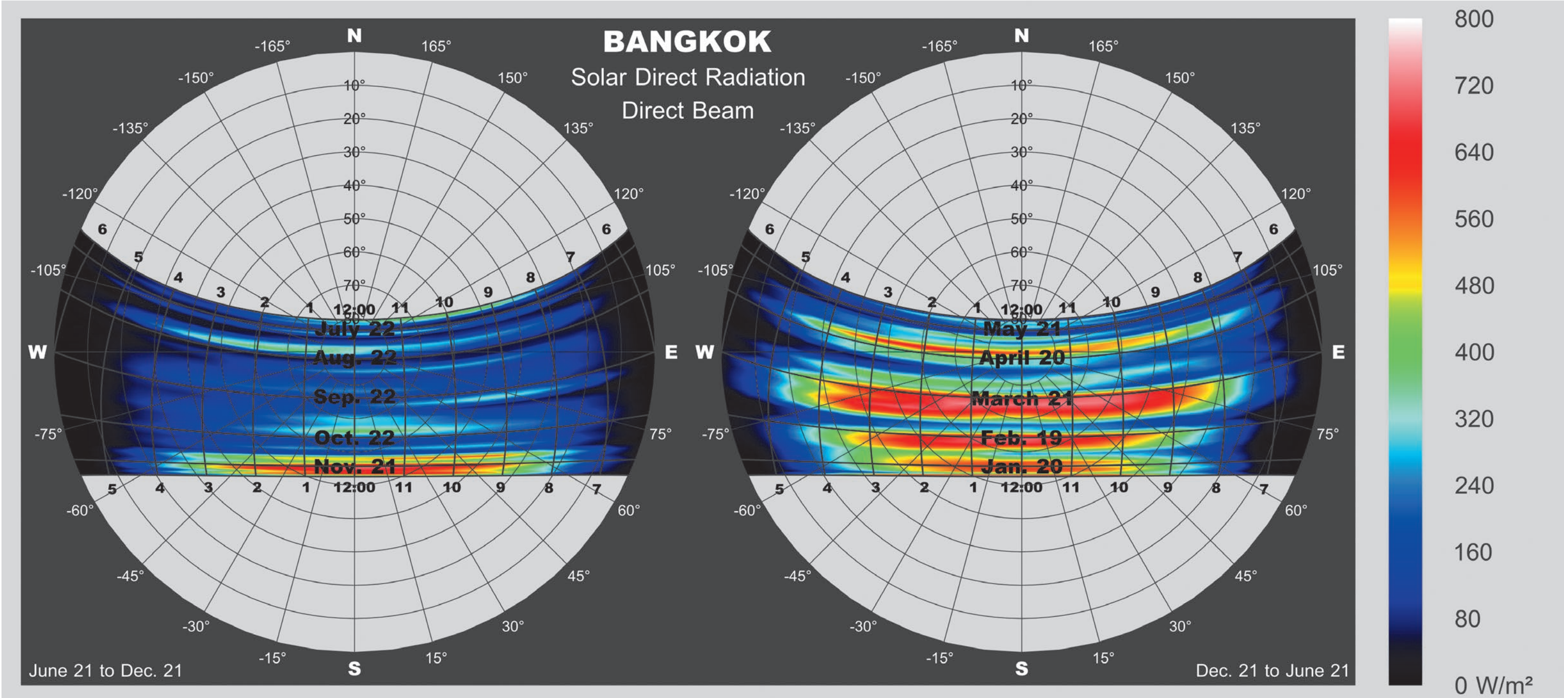


Fig. 20: SOLARCHVISION plot for 5-day average of direct beam radiation data for Tokyo (U.S. Department of Energy TMY files)
Fig. 21: Total daily radiation during the year for different surface orientations and inclinations in Tokyo

that there are sunny days between June and September as well as sunny days in winter, notably in February.

According to the 5-day average diagram of the hourly direct beam radiation for the city of Tokyo, the situation in the capital city of Japan is completely different to that in Tehran despite both cities being located on fairly similar latitudes, close to 35° N. As can be seen on the right side of the diagram, there are more sunny days in winter between January and March, whereas the weather is mostly cloudy or rainy in the other months. The humid weather condition of Tokyo, in comparison to the dry climate in Tehran, is another factor which reduces the maximum direct beam radiation to 600 W/m² on sunny days in Tokyo.



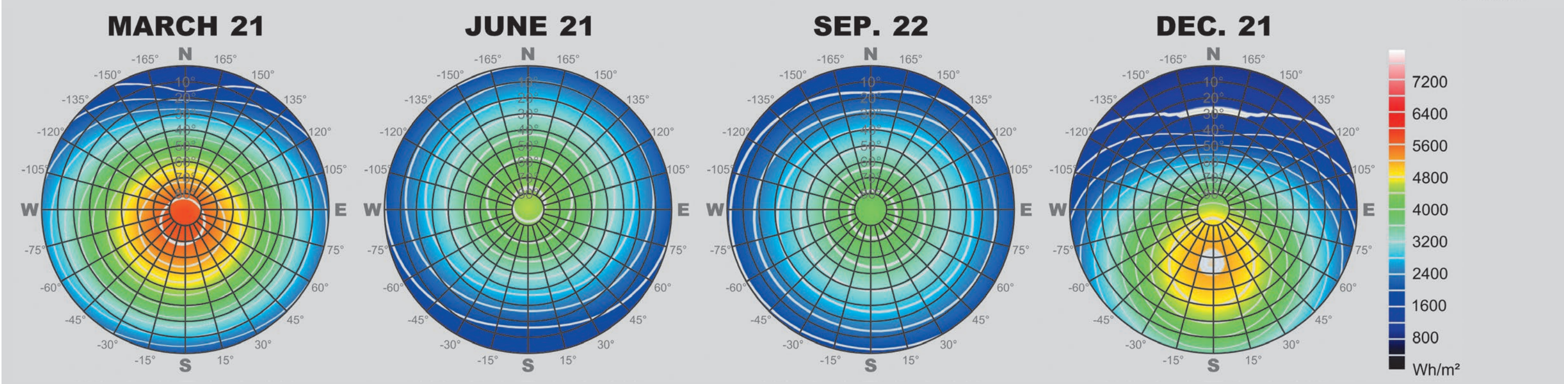
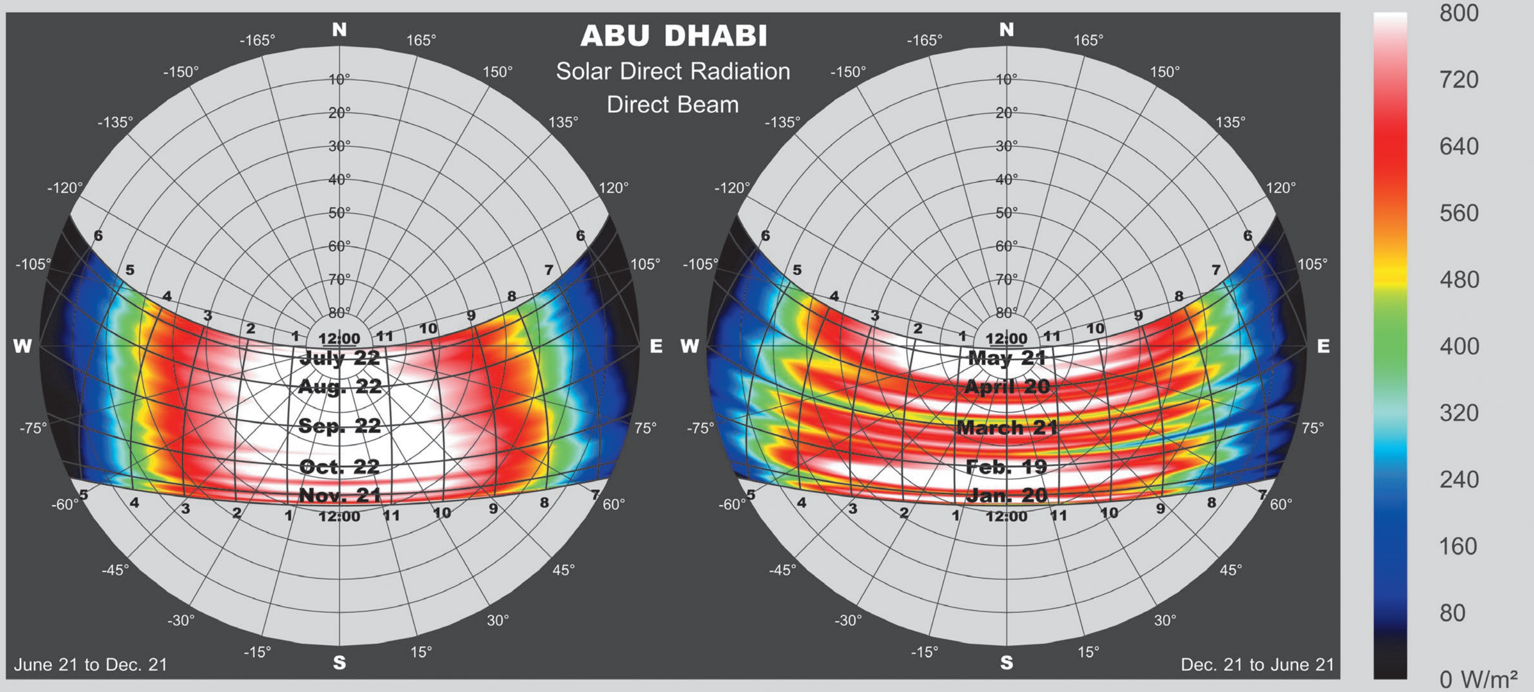


Fig. 22: SOLARCHVISION plot for 5-day average of direct beam radiation data for Bangkok (U.S. Department of Energy TMY files)
Fig. 23: Total daily radiation during the year for different surface orientations and inclinations in Bangkok

According to the 5-day average diagram of hourly direct beam radiation for the city of Bangkok, the situation in the capital city of Thailand is similar to that in Tokyo even though both cities are not located on the same latitude (22° difference in latitude). In contrast to general belief, the cities near the equator are not sunnier. As can be seen on the left side of the diagram, the amount of direct beam radiation is remarkably low as a result of the rainy seasons. Similar to Tokyo, there are more sunny days in winter, between January and March.



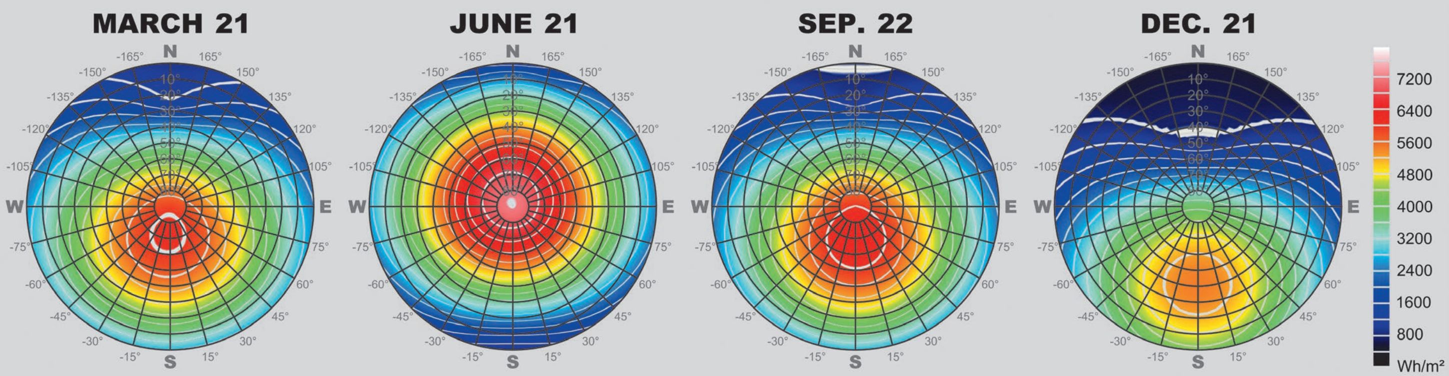


Fig. 24: SOLARCHVISION plot for 5-day average of direct beam radiation data for Abu Dhabi (U.S. Department of Energy TMY files)
Fig. 25: Total daily radiation during the year for different surface orientations and inclinations in Abu Dhabi

According to the 5-day average diagram of hourly direct beam radiation for the city of Abu Dhabi, the situation in the capital city of the United Arab Emirates is different to that in the previous cities. High values of direct beam radiation exceeding 800 W/m² are measured between 10 a.m. and 2 p.m. throughout all months of the year.

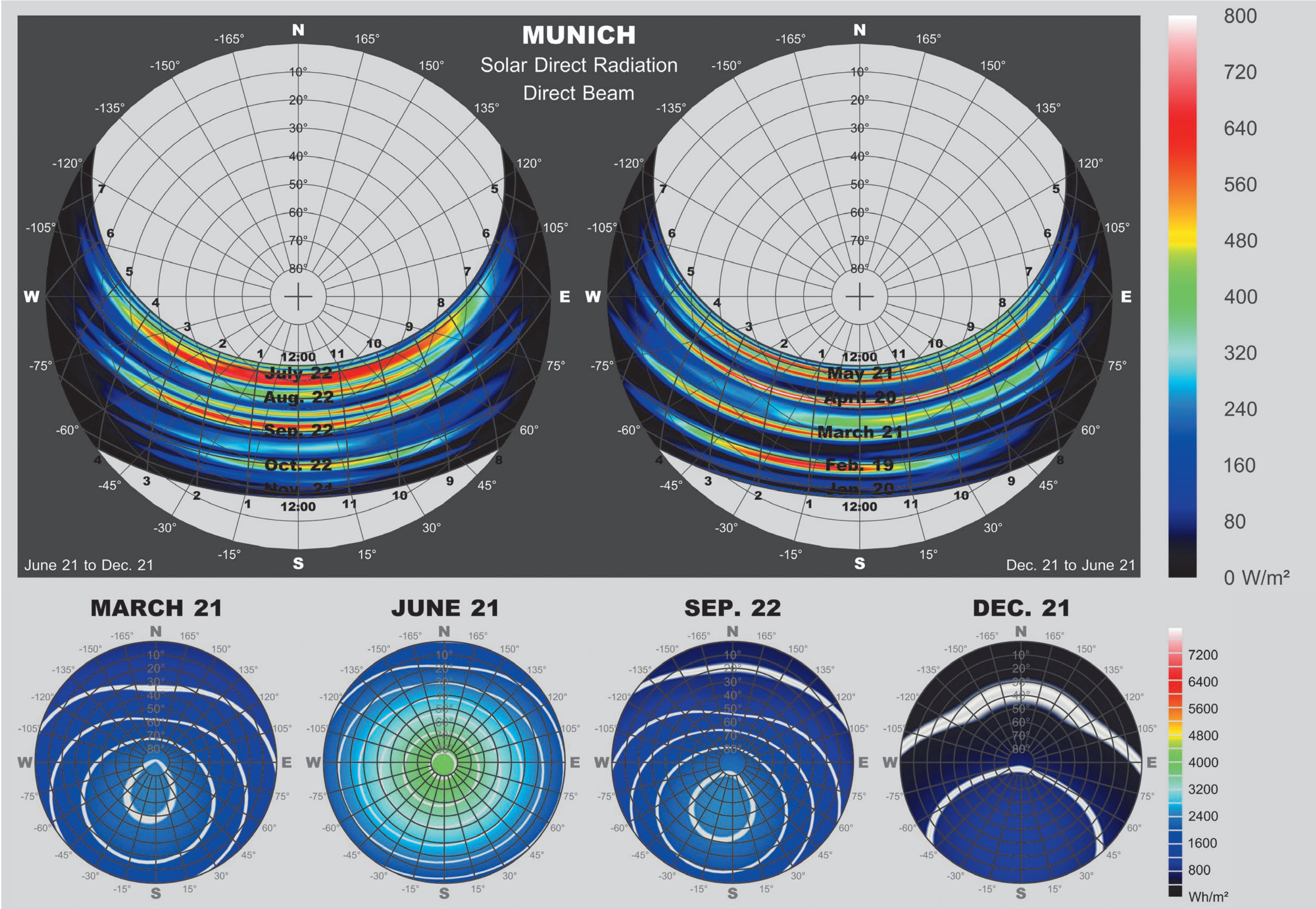
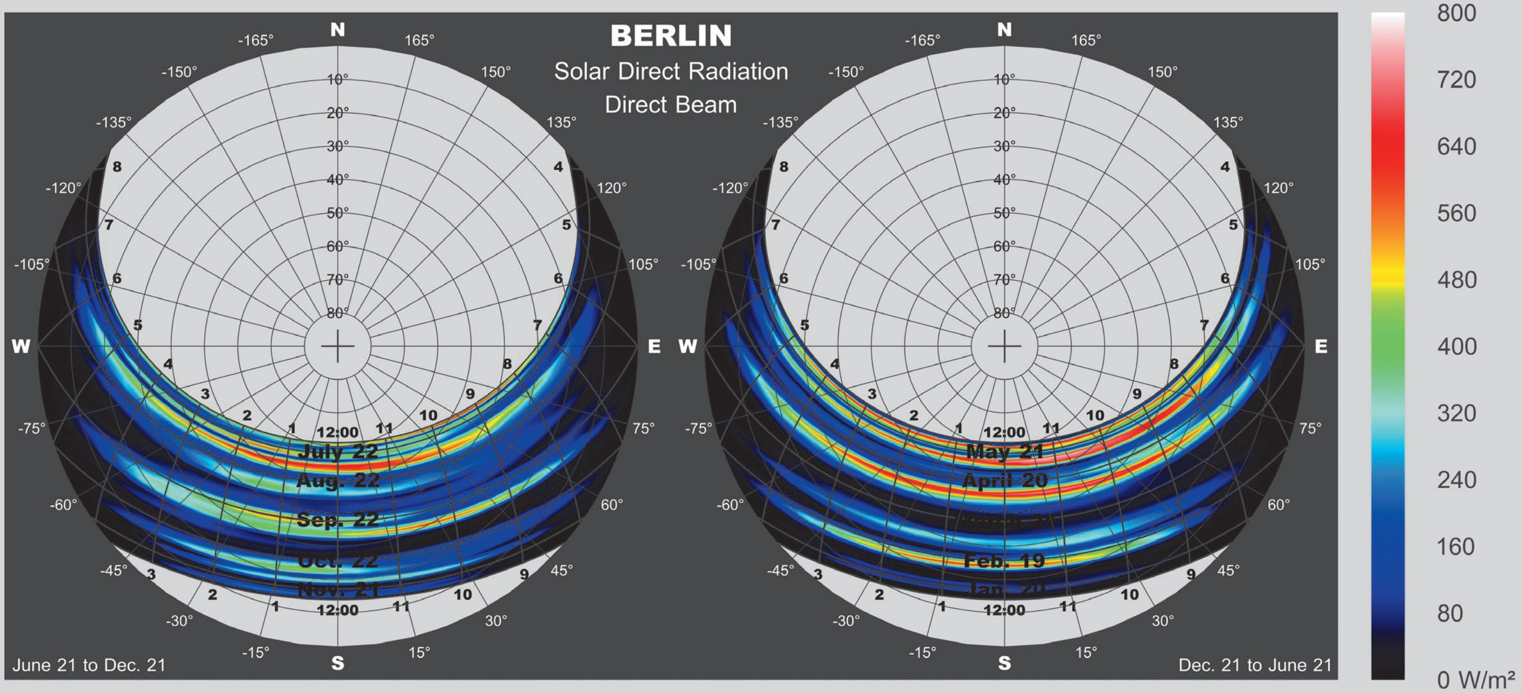


Fig. 26: SOLARCHVISION plot for 5-day average of direct beam radiation data for Munich (U.S. Department of Energy TMY files)
Fig. 27: Total daily radiation during the year for different surface orientations and inclinations in Munich

According to the 5-day average diagram of hourly direct beam radiation for the city of Munich in Germany, the Typical Meteorological Year (TMY) shows both sunny and cloudy situations for different months of the year. In contrast to the situation in Tokyo, direct solar radiation reduces in winter. On the other hand, there are more sunny days during summer than in Tokyo. The humid weather conditions in Munich are a further factor reducing the maximum direct beam radiation to 600 W/m² on sunny days.



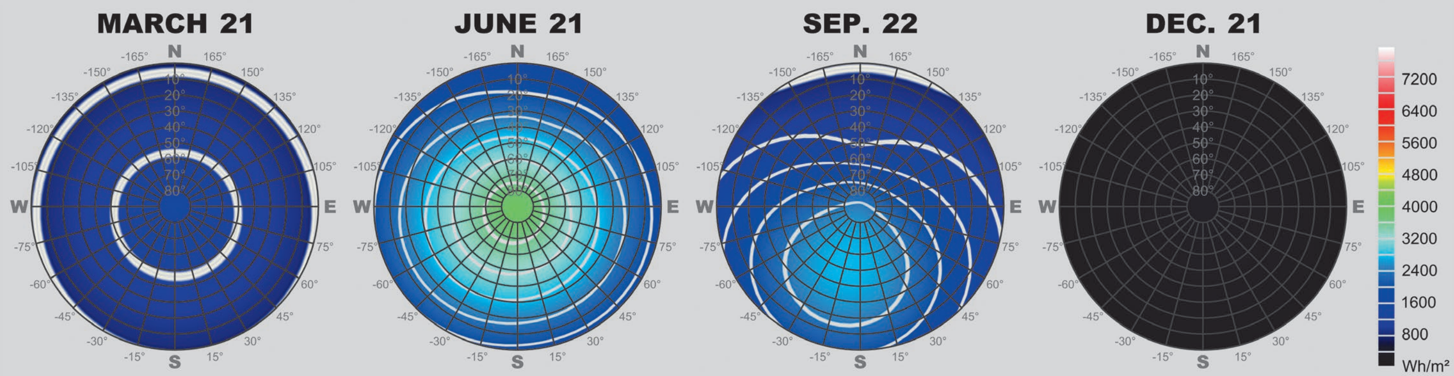


Fig. 28: SOLARCHVISION plot for 5-day average of direct beam radiation data for Berlin (U.S. Department of Energy TMY files)
Fig. 29: Total daily radiation during the year for different surface orientations and inclinations in Berlin

According to the 5-day average diagram of hourly direct beam radiation for the city of Berlin in Germany in a Typical Meteorological Year (TMY), the situation is different to that in Munich. There are fewer sunny days, especially around 21 March. As a result of its higher latitude, Berlin has longer days in summer and shorter days in winter in comparison to Munich.

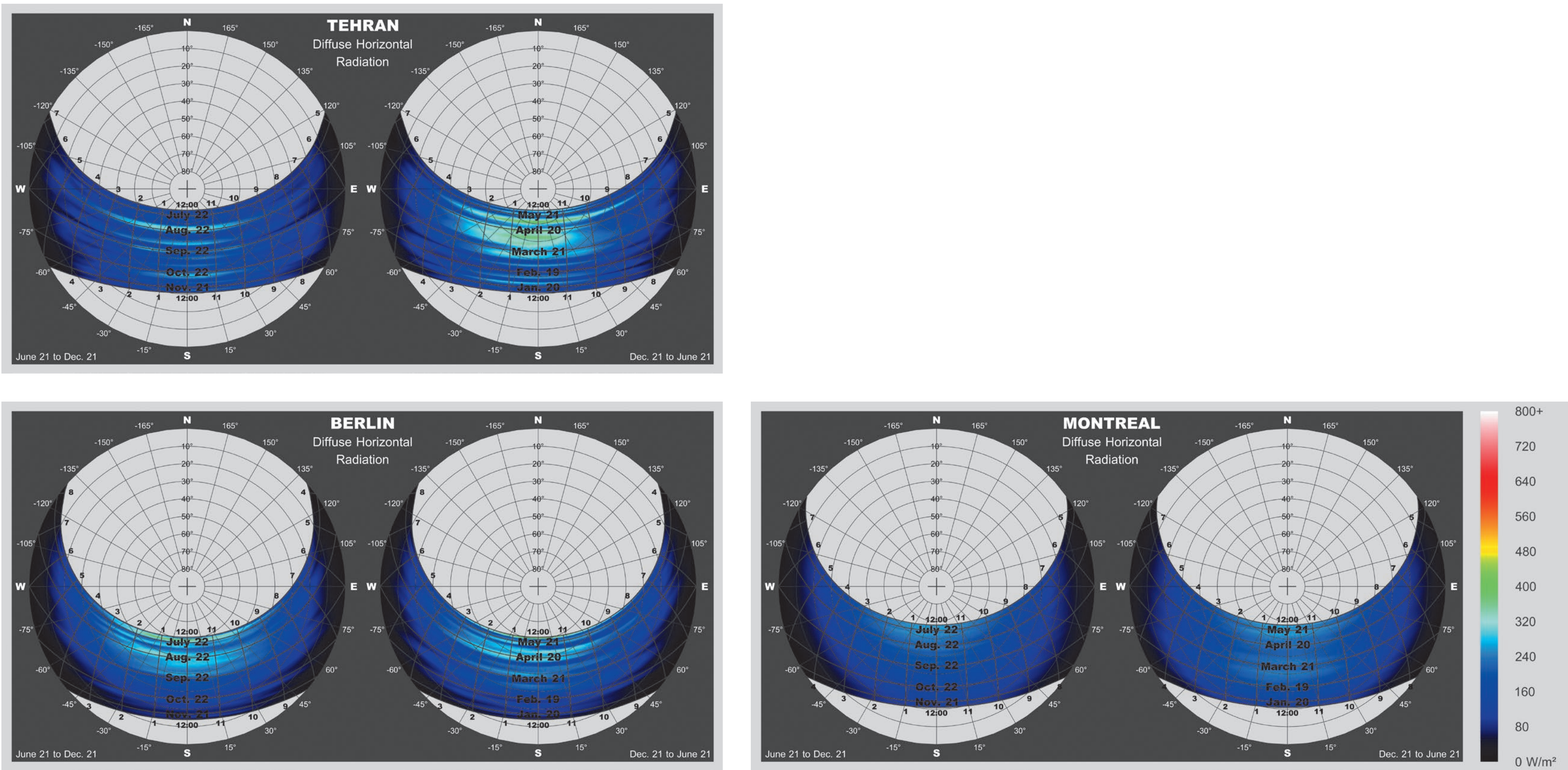


Fig. 30–32: SOLARCHVISION plot for 5-day average of diffuse horizontal radiation data of Tehran (TMY: Meteonorm 6.0), Berlin (TMY: U.S. Department of Energy) and Montréal (standardized between 1953 and 2005 from CWEEDS file of Jean-Brebeuf station)

Figures 30–32 show the 5-day average diagram of hourly horizontal diffuse radiation for the cities of Tehran and Berlin in a Typical Meteorological Year (TMY) as well as the long-term average data of Montréal between 1953 and 2005.

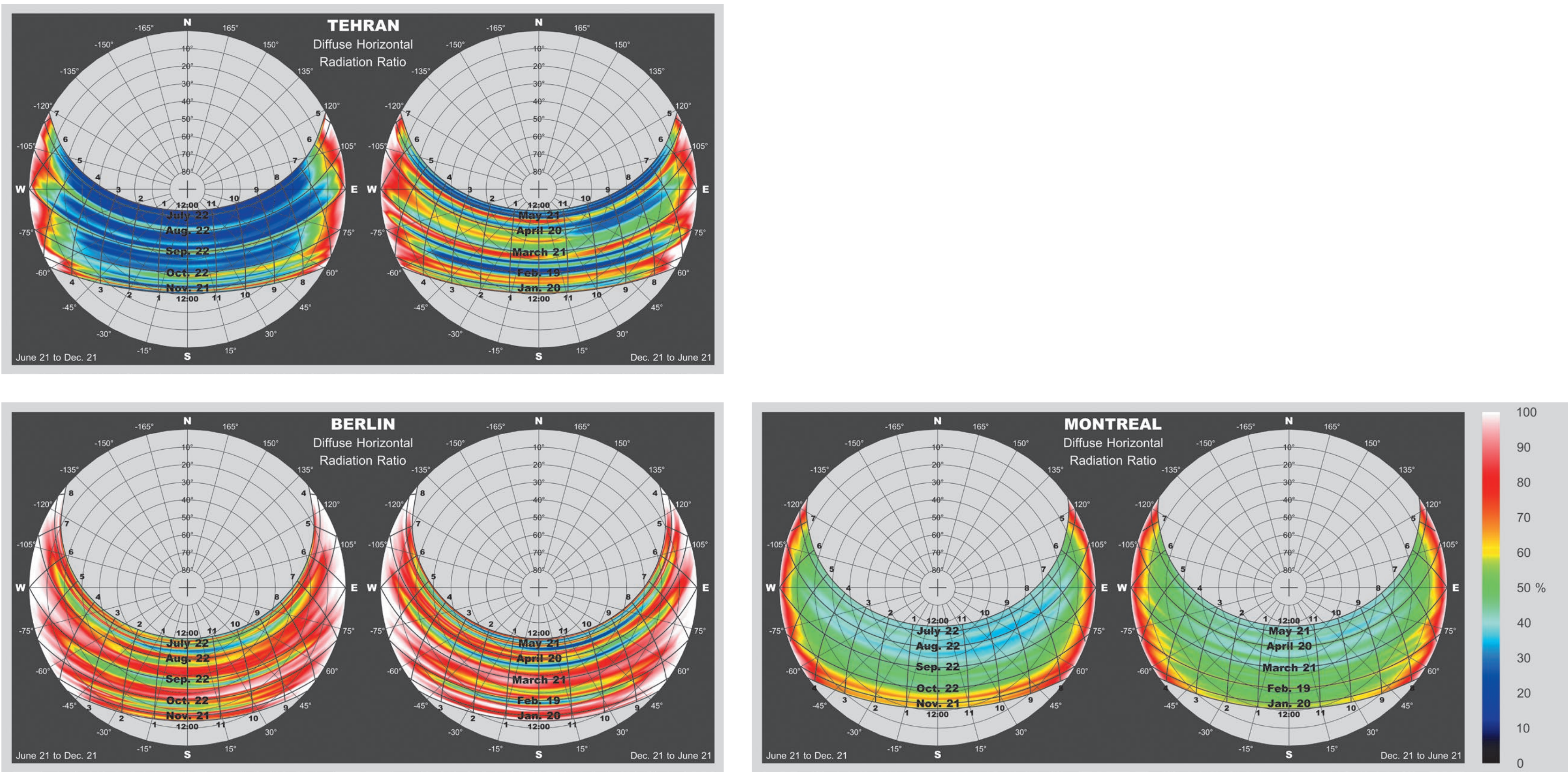


Fig. 33–35: SOLARCHVISION plot for Percentage of diffuse horizontal radiation in relation to the total horizontal radiation of Tehran (TMY: Meteonorm 6.0), Berlin (TMY: U.S. Department of Energy) and Montréal (standardized between 1953 and 2005 from CWEEDS file of Jean-Brebeuf stationes—station: Montréal (Jean-Brebeuf))

The diagrams above show the percentage of diffuse horizontal radiation in relation to the total horizontal radiation. The differences between the ratios of diffuse and direct radiation are illustrated for each location. As is highlighted in these diagrams, the ratio of diffuse radiation increases around sunrise and sunset. Besides, diffuse radiation plays a more important role in humid and cloudy cities like Berlin in comparison to dry and sunny cities, like Tehran.

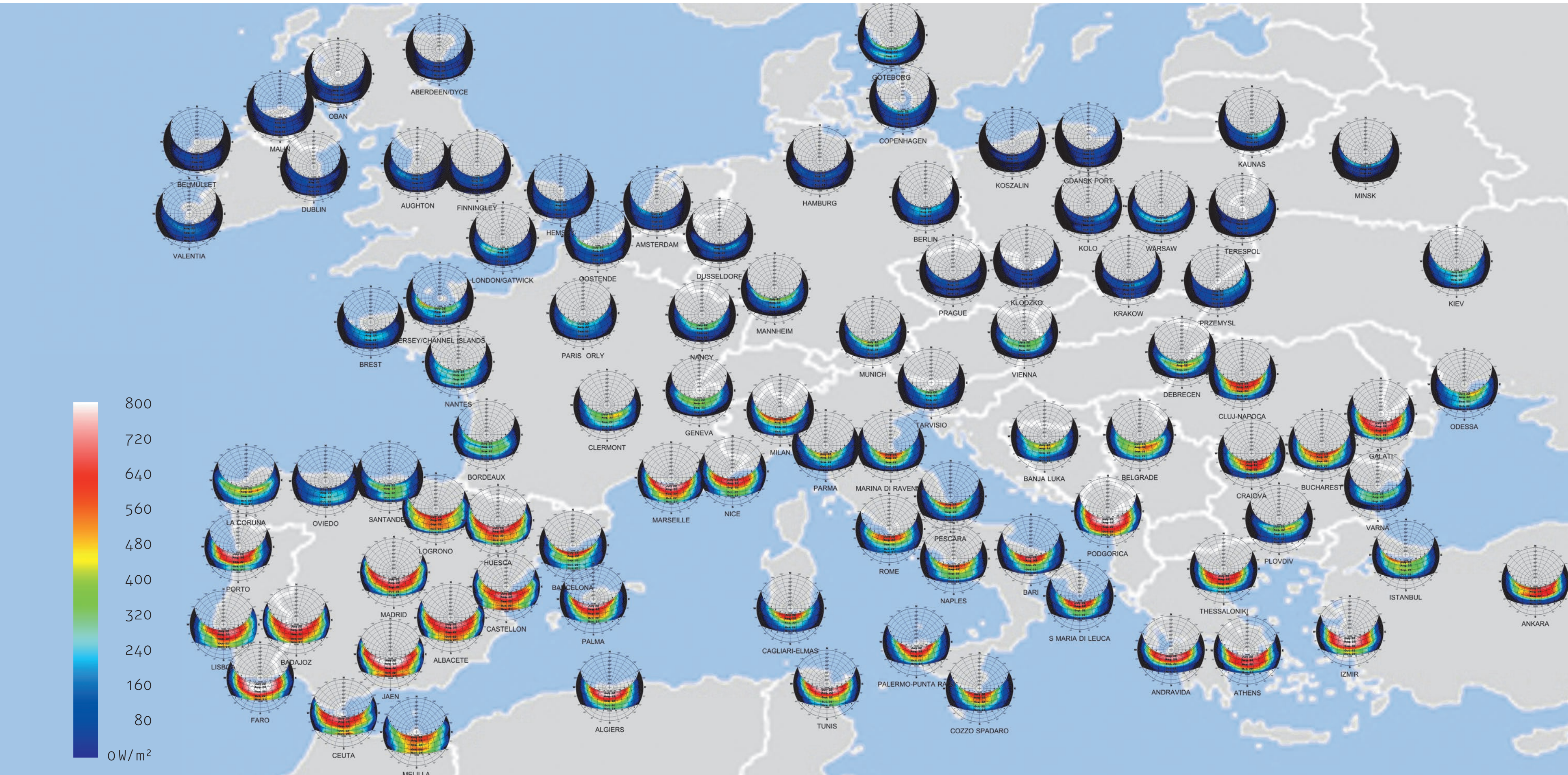


Fig. 36: SOLARCHVISION plot for average hourly direct beam radiation from June 21 to December 21 in Europe (U.S. Department of Energy TMY files)

Based on the data of a Typical Meteorological Year, the monthly average diagram with the hourly amounts of direct beam radiation for different European cities for the period 21 June to 21 December illustrates the availability of direct solar radiation in each location. As can be discovered from the diagram, several cities in Spain as well as Portugal, the southern part of France, Montenegro, Romania, Bulgaria, Greece and Italy receive a remarkable amount of direct solar radiation in comparison to cities in northern Europe.

Fig. 37: SOLARCHVISION plot for average hourly direct beam radiation from December 21 to June 21 in Europe (U.S. Department of Energy TMY files)

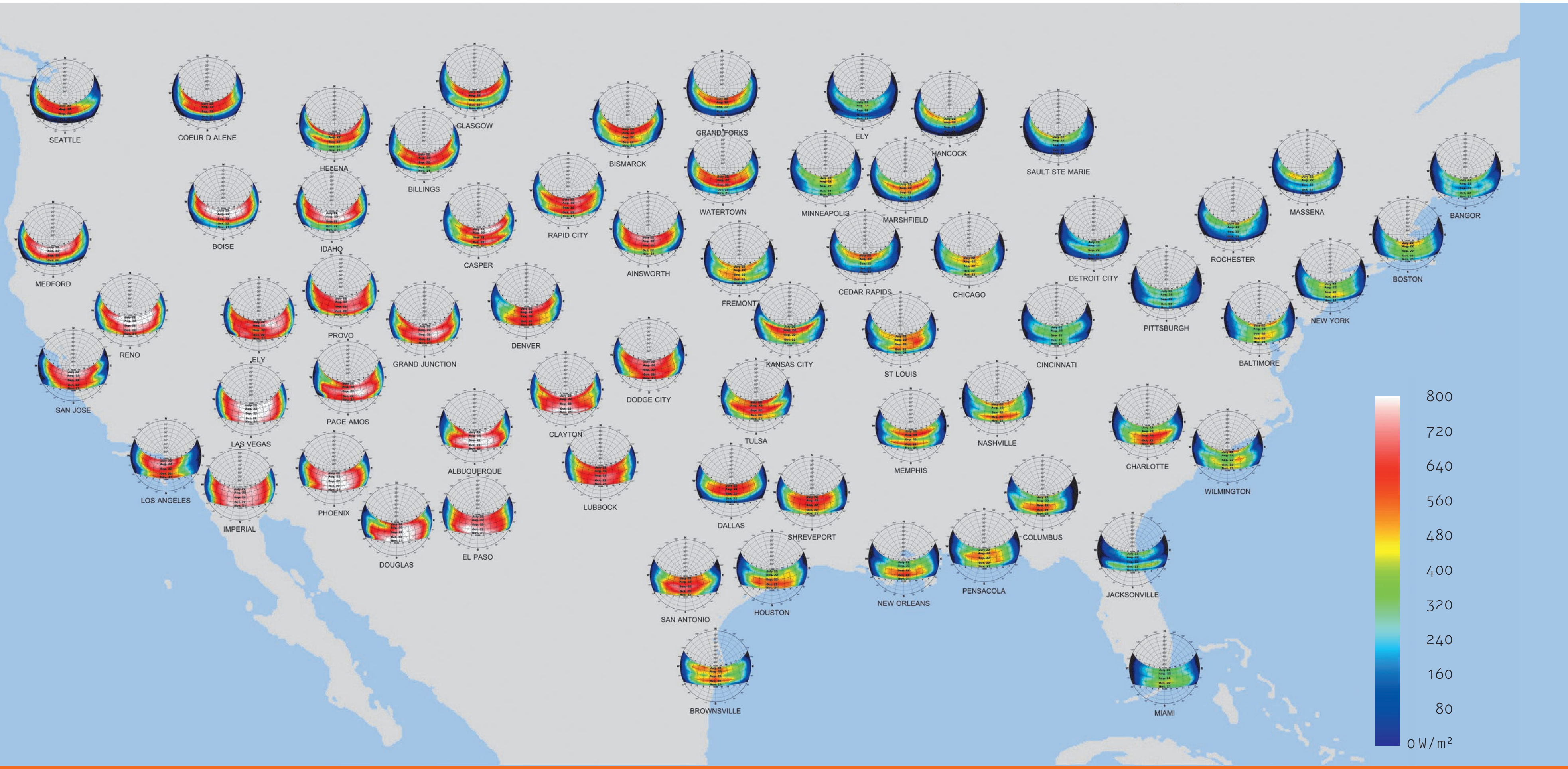


Fig. 38: SOLARCHVISION plot for average hourly direct beam radiation from June 21 to December 21 in the USA (U.S. Department of Energy TMY files)

Based on the data of a Typical Meteorological Year, the monthly average diagram with the hourly amount of direct beam radiation for different cities in the USA for the period 21 June to 21 December illustrates different situations for the east and west side of the country. In contrast to the general rule that latitude plays the most essential role regarding the solar condition in each location, this diagram shows that the effect of longitude should also be considered as the western side of the USA receives more direct solar radiation than the eastern side. One of the sunniest cities of the USA, according to this diagram, is Las Vegas which is located in the state of Nevada.

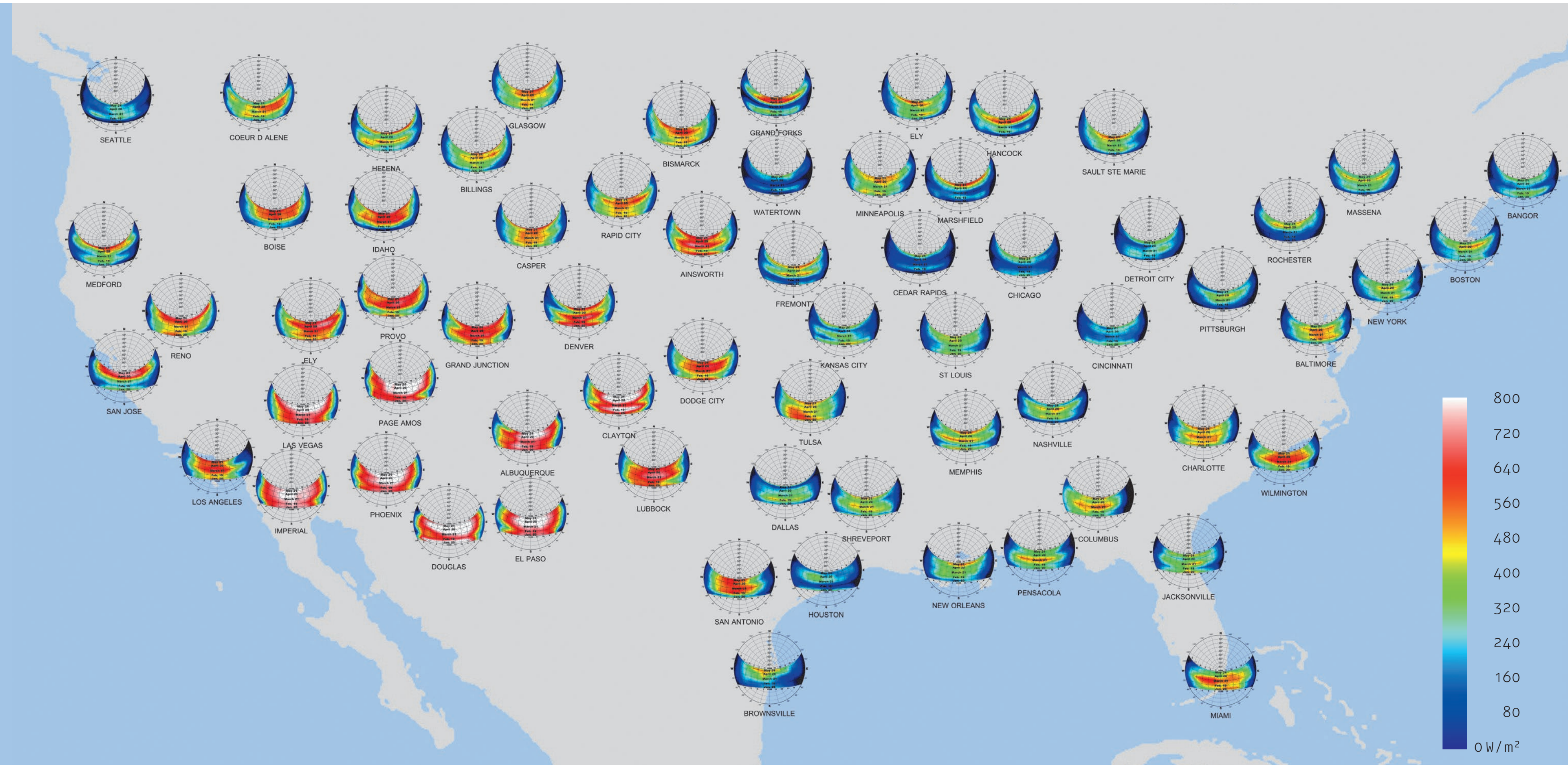


Fig. 39: SOLARCHVISION plot for average hourly direct beam radiation from December 21 to June 21 in the USA (U.S. Department of Energy TMY files)

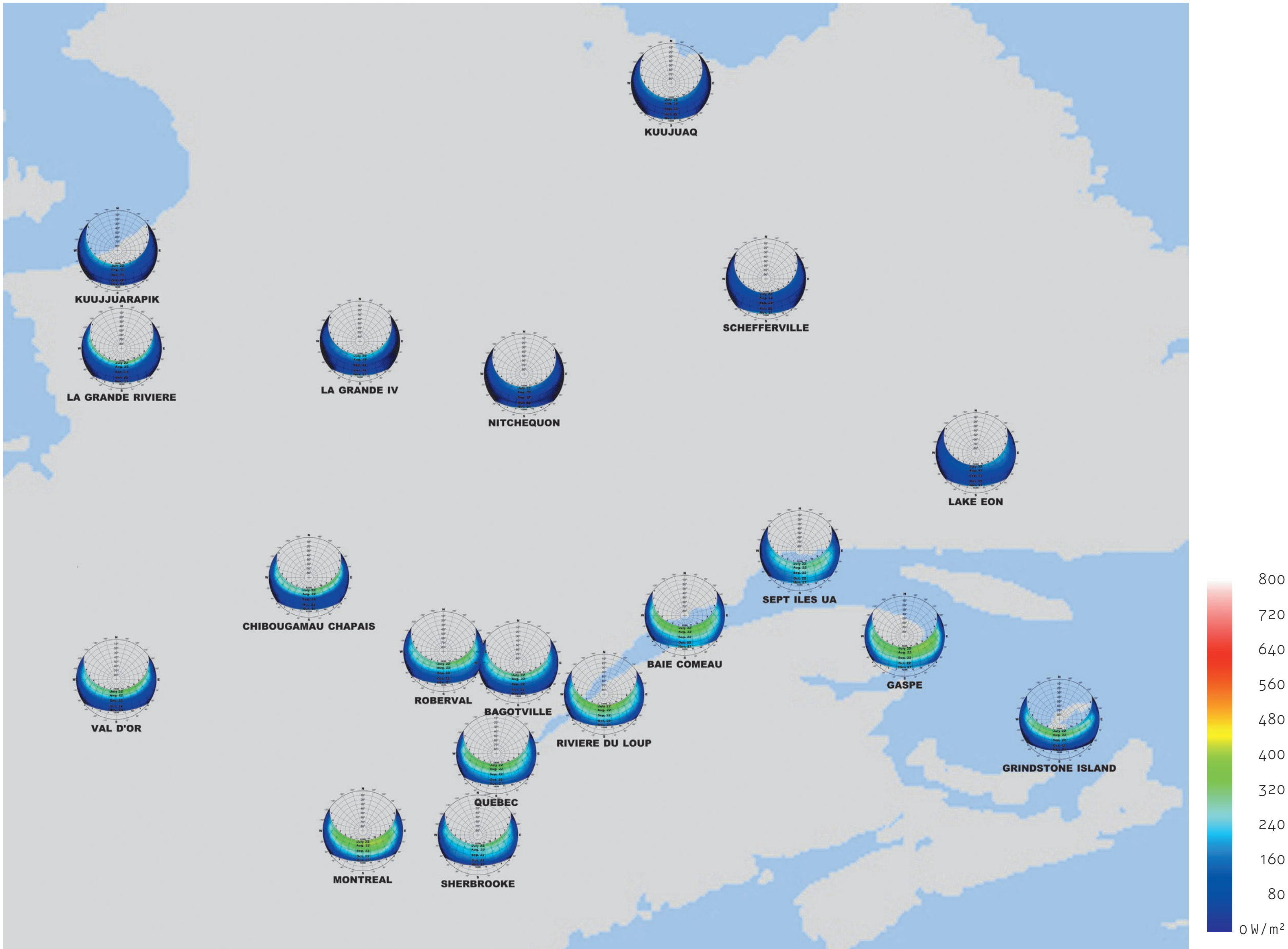


Fig. 40: SOLARCHVISION plot for average hourly direct beam radiation (from June 21 to December 21) between 1953 and 2005 in Québec, Canada (National Climate Data and Information Archive of Canada—CWEEDS files)

The average monthly model with the hourly direct beam radiation of different Canadian cities in the province of Québec for the period 21 June to 21 December illustrates the availability of direct solar radiation in the southern and northern parts of the country. As the model illustrates, the amount of direct beam radiation is higher in the southern cities of Montréal and Gaspé between 21 June and 21 December.

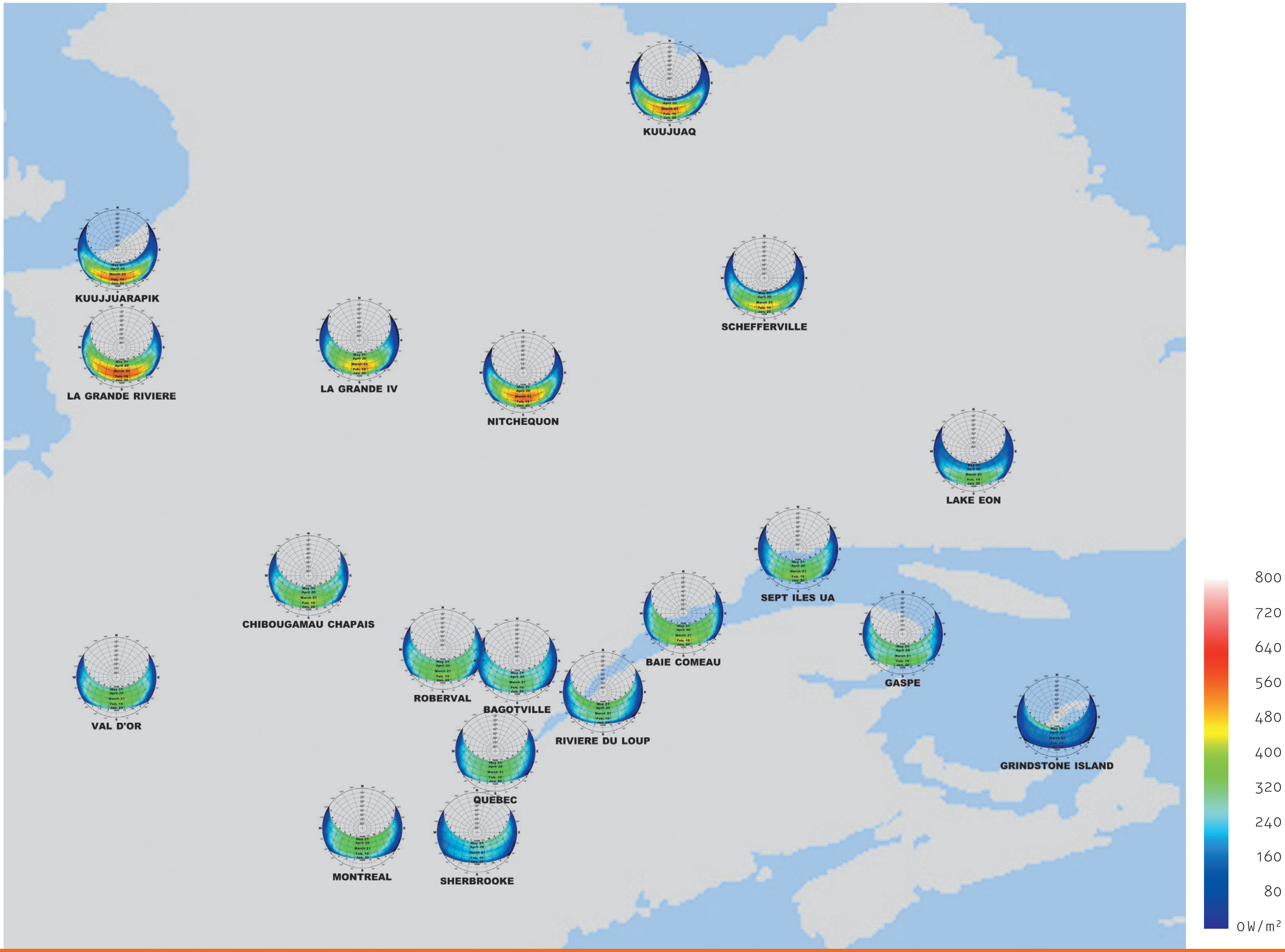
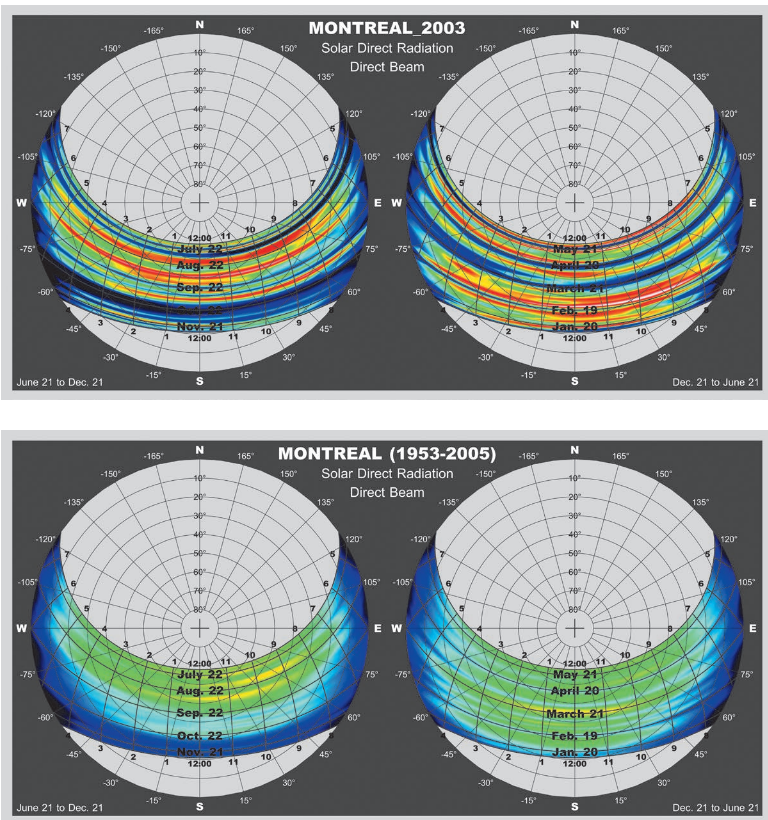


Fig. 41: SOLARCHVISION plot for average hourly direct beam radiation (from December 21 to June 21) between 1953 and 2005 in Québec, Canada (National Climate Data and Information Archive of Canada—CWEEDS files)

For the other part of the year, between 21 December and 21 June, the following average monthly model with the hourly direct beam radiation of different Canadian cities in the province of Québec shows a completely different situation. As can be discovered from the model, the amount of direct beam radiation is higher in the northern cities between 21 December and 21 June. This can be the result of the many sunny cold days with extremely low temperatures in the northern areas. These extreme temperature conditions are also illustrated in Figure 51.

Figures 42–43 present the 5-day average of hourly direct beam radiation for the city of Montréal in Canada. The first diagram is based on data from 2003, whereas the second one presents the long-term data of 53 years, for the period 1953 and 2005. The remarkable difference between the two diagrams shows how extreme conditions can occur in a single location. For instance in 2003, the amount of direct beam radiation exceeded 650 W/m² on several days of the year, both in summer and winter; however, the maximum normal long-term value for this parameter is about 500 W/m².

Figures 44–45 present the 5-day average of hourly direct beam radiation for the city of Montréal in the 70s and 90s. A comparison of the



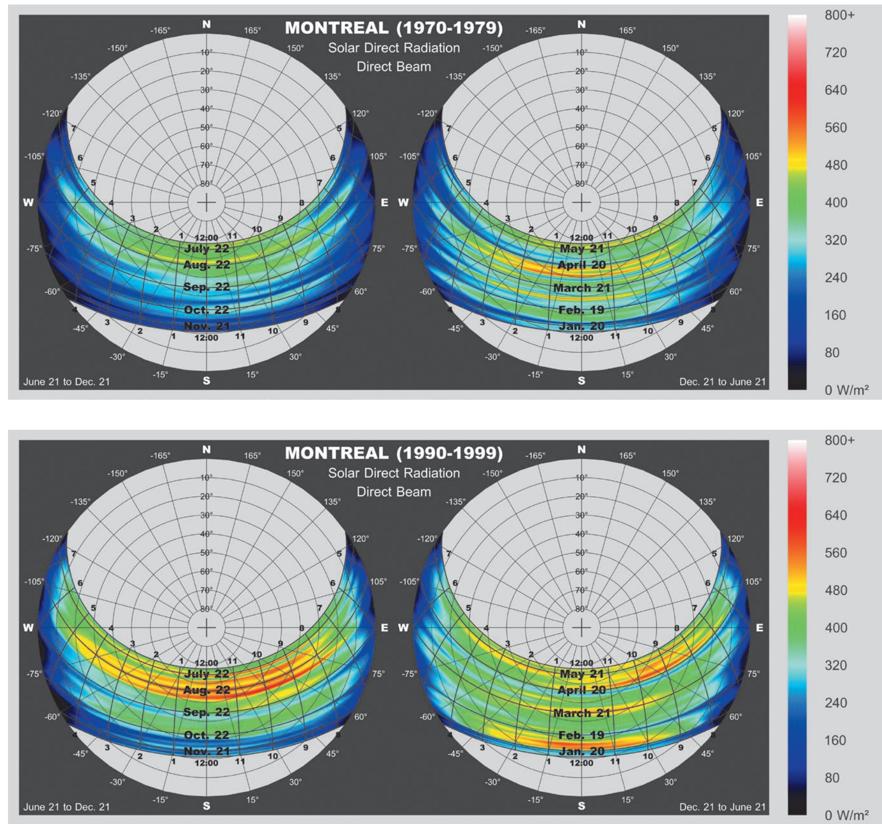


Fig. 42–43: SOLARCHVISION plot for 5-day average of direct beam radiation data in Montréal, above: 2003, below: standardized between 1953 and 2005

Fig. 44–45: Changes in the direct beam radiation patterns of Montréal in two decades, above: 70s, below: 90s (Jean-Brebeuf CWEEDS file)

two diagrams shows a remarkable increase of solar radiation in Montréal, which could be due to the global warming phenomenon. For instance, the normal value of direct beam radiation in August increased from 475 W/m² in the 70s to 650 W/m² in the 90s. In February, the normal value of direct beam radiation also rose from 400 W/m² in the 70s to 550 W/m² in the 90s.

The following diagrams present the 5-day average of hourly temperature for the city of Montréal in Canada in the 70s and 90s. A comparison of the two diagrams for Montréal shows an increase in temperature. It is noticeable that in winter the black and gray colors, which present low temperatures between -10°C and -15°C, are replaced by a range of white, which presents temperatures around -7°C. It is also worth noting that the red and yellow section lines illustrate the values of +21°C and 0°C. A more remarkable change has occurred to the 0°C section lines between these two periods. Even though the short winters might be good news for many people living in the cold climate of Montréal, the climate change is, in the long term and on a global scale, subject of concern and discussion among many scientists.

The SOLARCHVISION calculations highlight a remarkable increase in the monthly average minimum temperature in winter from -13.7°C to -10.9°C between the 70s and 90s. On the other hand, there is also an increase in the monthly average maximum temperature in summer, from +24.9°C to +25.3°C. Consequently, these increases in temperature, as well as in the direct solar radiation, could be the result of the global warming phenomenon or the heat island effect in cities. Similar studies can also help to discover and highlight climate change in other places around the world in the same way.

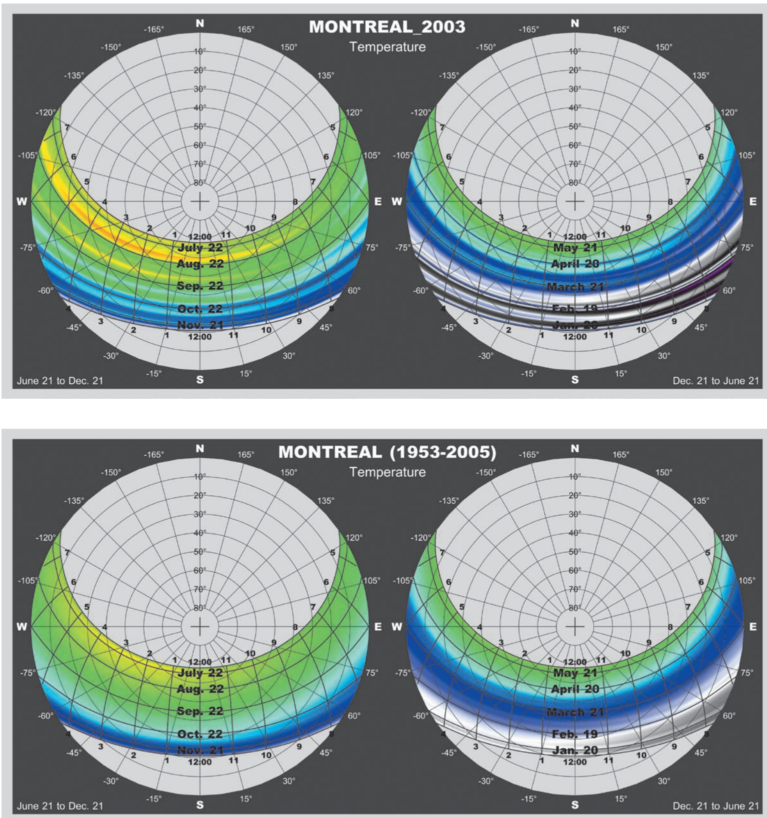


Fig. 46–47: SOLARCHVISION plot for 5-day average of temperature data in Montréal, above: 2003, below: standardized between 1953 and 2005

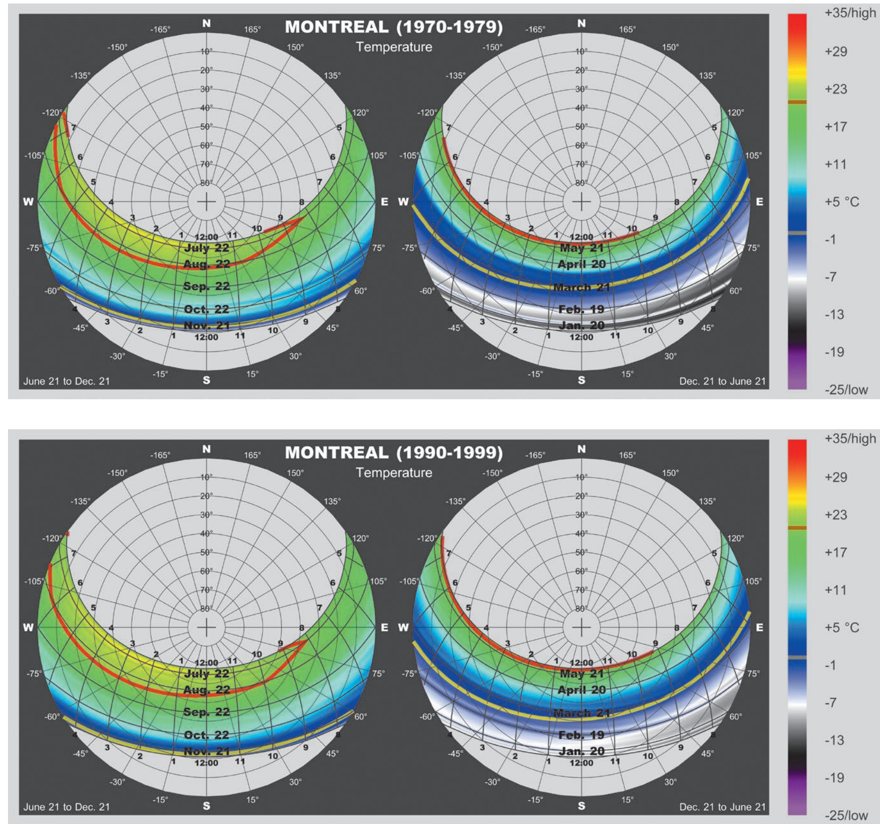


Fig. 48–49: Changes in the temperature patterns of Montréal in two decades, above: 70s, below: 90s (Jean-Brebeuf CWEEDS file)

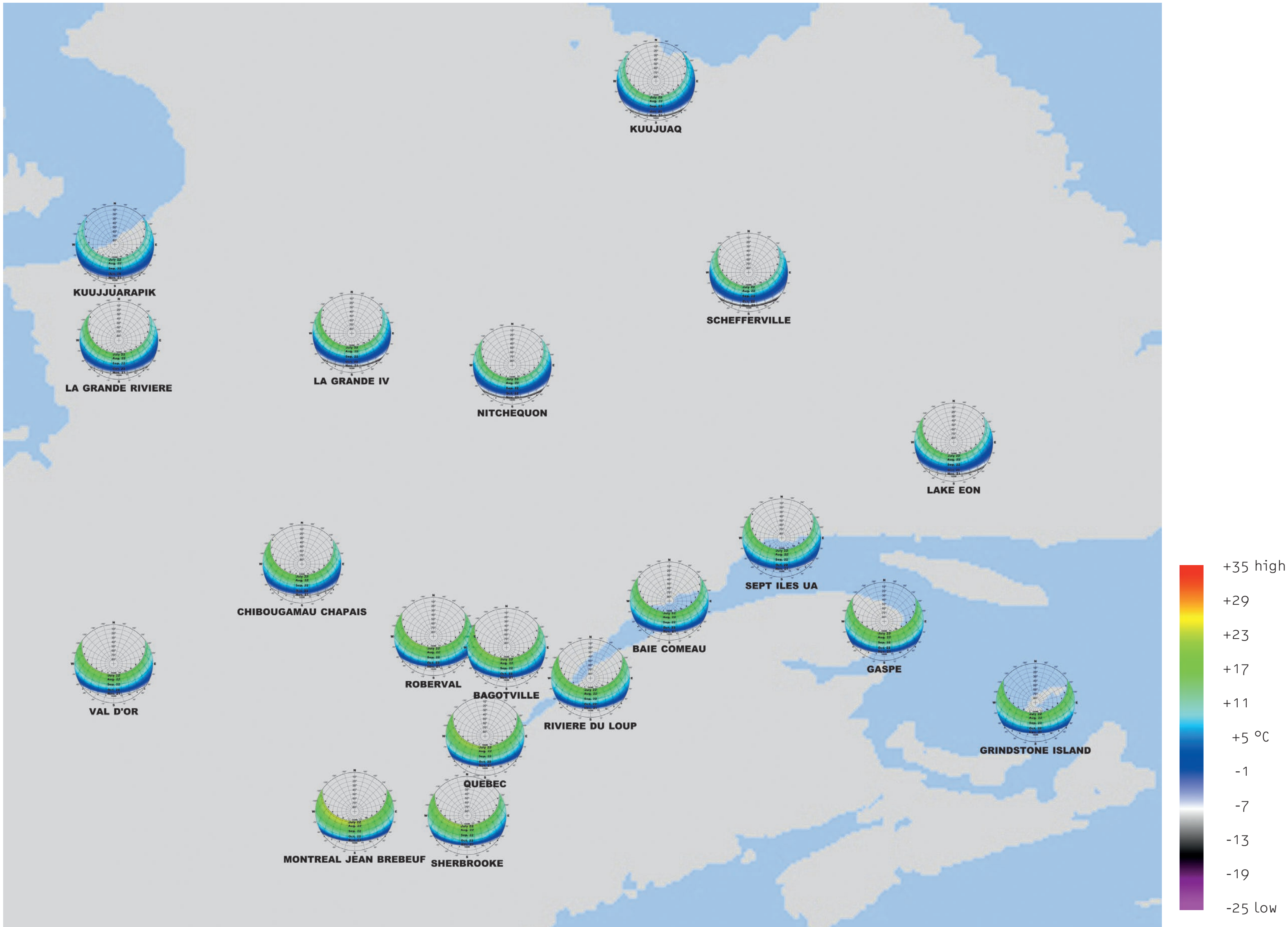


Fig. 50: SOLARCHVISION plot for average hourly temperature (from June 21 to December 21) between 1953 and 2005 in Québec, Canada (National Climate Data and Information Archive of Canada—CWEEDS files)

The following diagram presents changes in temperature in the province of Québec in Canada during the period 21 June to 21 December. According to this diagram, the conditions are more comfortable in summer in Québec (Canada); however, it already starts to get colder during autumn (from 22 September to 21 December) and sometimes even snows.

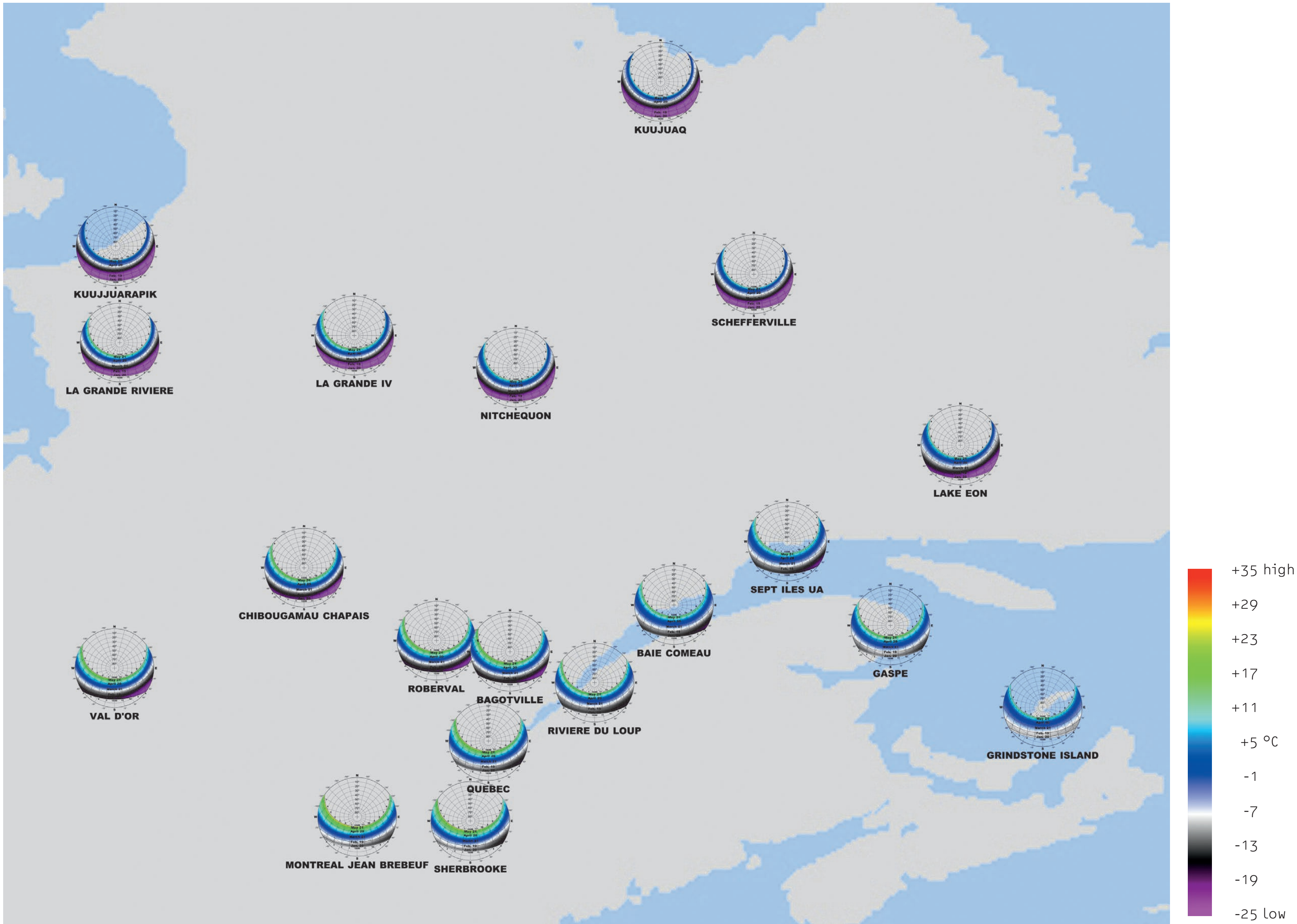


Fig. 51: SOLARCHVISION plot for average hourly temperature (from December 21 to June 21) between 1953 and 2005 in Québec, Canada (National Climate Data and Information Archive of Canada—CWEEDS files)

On the other hand, the extreme cold highlighted in the Figure 51 during winter and spring in Québec (Canada) is quite clearly in places with higher latitudes. A number of well-known cities in Canada, including Montréal, Ottawa and Toronto, are located close to the 45°N latitude and below, which is the same latitude as cities in northern Italy, Europe, like Milan; however, the winters in Canada are not comparable with those in Italy due to the differences in geographical and atmospheric conditions.

Similarly, the conditions in the central areas of Québec, like Nitchequon, are significantly colder than those of European cities on similar latitudes, such as Berlin.

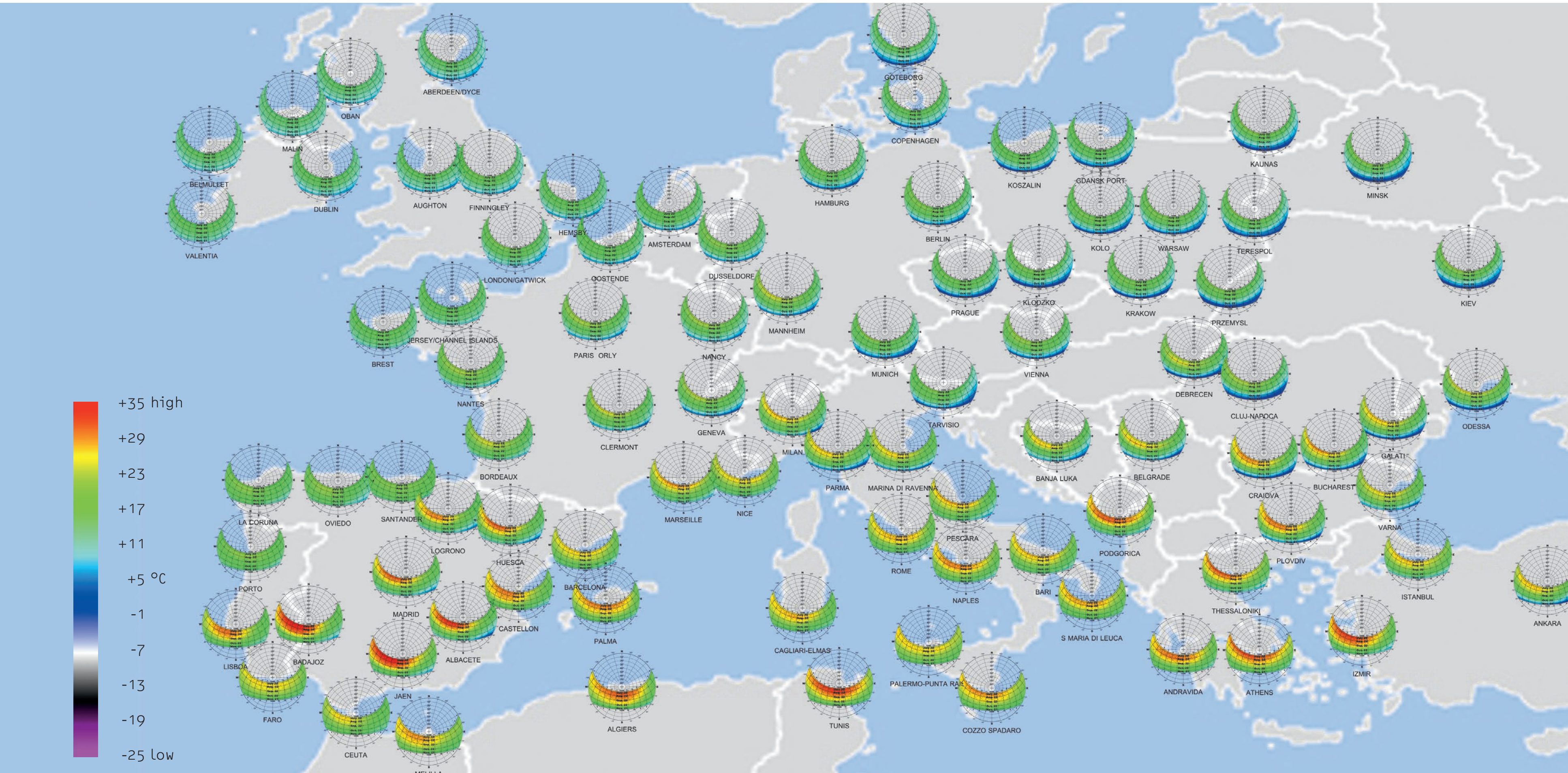


Fig. 52: SOLARCHVISION plot for average hourly temperature from June 21 to December 21 in Europe (U.S. Department of Energy TMY files)

As the general patterns of change in hourly temperature for the period 21 June to 21 December based on TMY files show, most of the northern cities in Europe have temperatures near the comfort zone for most days in summer and autumn, as plotted in green; however, the southern cities have warmer conditions during summer, which is illustrated in red. Some countries, mostly those located in north-east Europe, also have cold weather from the middle of autumn, as plotted in blue.

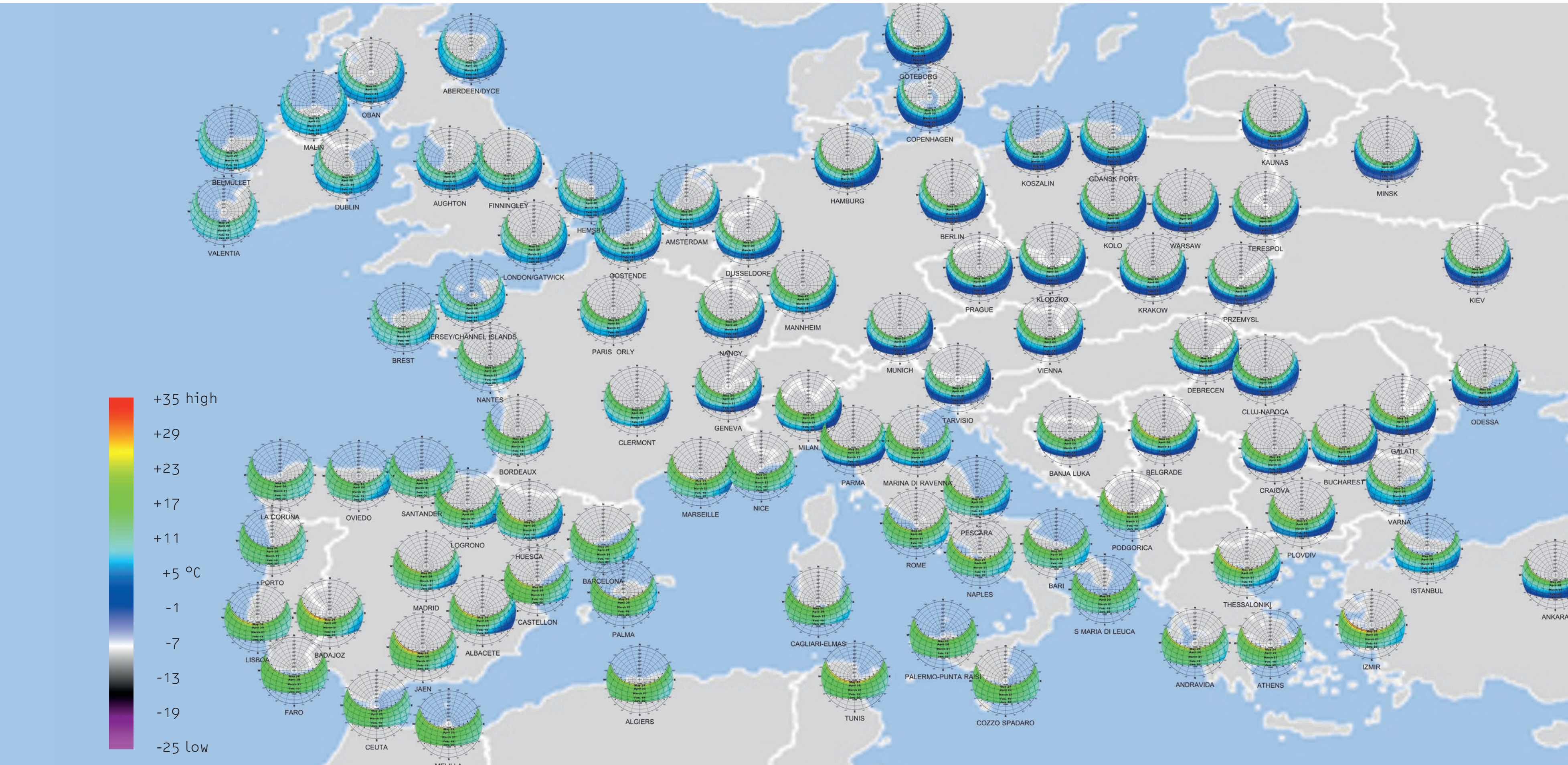


Fig. 53: SOLARCHVISION plot for average hourly temperature from December 21 to June 21 in Europe (U.S. Department of Energy TMY files)

On the other hand, changes in the daily temperature in winter and spring account for different patterns in each location in comparison to those in summer and autumn. As Figure 53 illustrates, most southern European cities have temperatures within or near the comfort zone on most days in winter and spring. In contrast, the northern cities have cold winters as plotted in blue and cool springs as plotted in cyan. Again, a colder and longer winter is the case for the eastern part of northern Europe, between Munich in Germany and Kiev in Ukraine. The climate in Ireland is almost temperate, and winters are not very cold even though it is located above a latitude of 50° N.

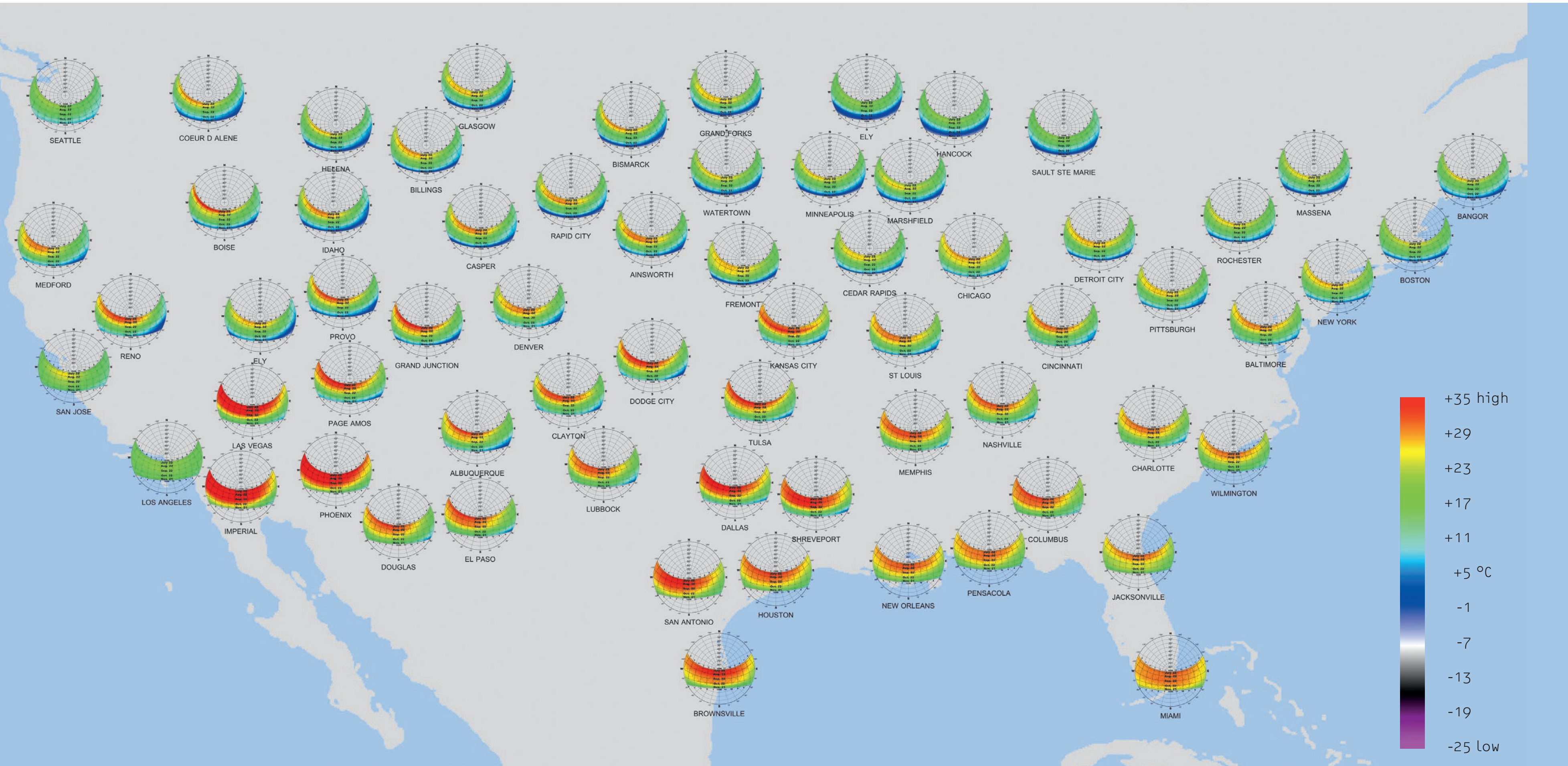


Fig. 54: SOLARCHVISION plot for average hourly temperature from June 21 to December 21 in the USA (U.S. Department of Energy TMY files)

Based on the data of a Typical Meteorological Year, the average monthly model of hourly outdoor temperatures for different cities in the USA for the period 21 June to 21 December illustrates different situations in the southern and northern parts of the country. As the model shows, the length of the summer in some parts of the country increases as the latitude decreases.

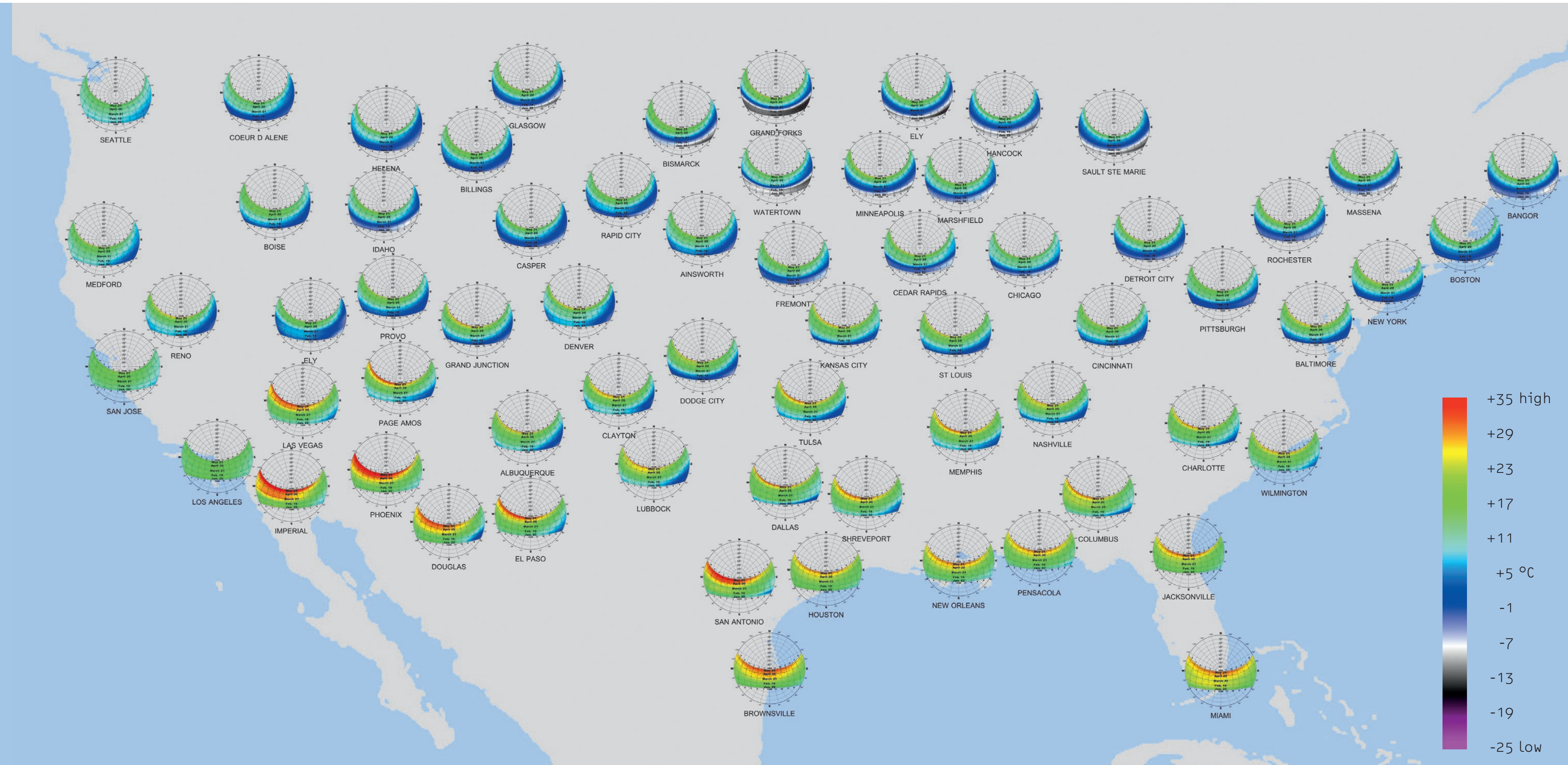


Fig. 55: SOLARCHVISION plot for average hourly temperature from December 21 to June 21 in the USA (U.S. Department of Energy TMY files)

The following diagram shows the different patterns of change in daily temperature between December 21 and June 21 in the USA based on the TMY data of each city. According to this diagram, the length of winter increases at higher latitudes. On the other hand, southern cities have more comfortable temperatures in winter as printed in green. Interestingly, during most of the period, the cities Los Angeles and San Jose, on the west coast, have temperature conditions close to the comfort zone. It can also be noted that the temperature rises after sunrise and during the day. This fact highlights the relation between sunshine and hourly changes in temperature; moreover, the pattern of relative humidity is a remarkable factor which affects both the direct radiation and temperature differences/fluctuations in each location.

Fig. 56: Average hourly temperature in Iran (from 21 June to 21 December) based on long-term daily minimum and maximum temperature averages calculated by SOLARCHVISION

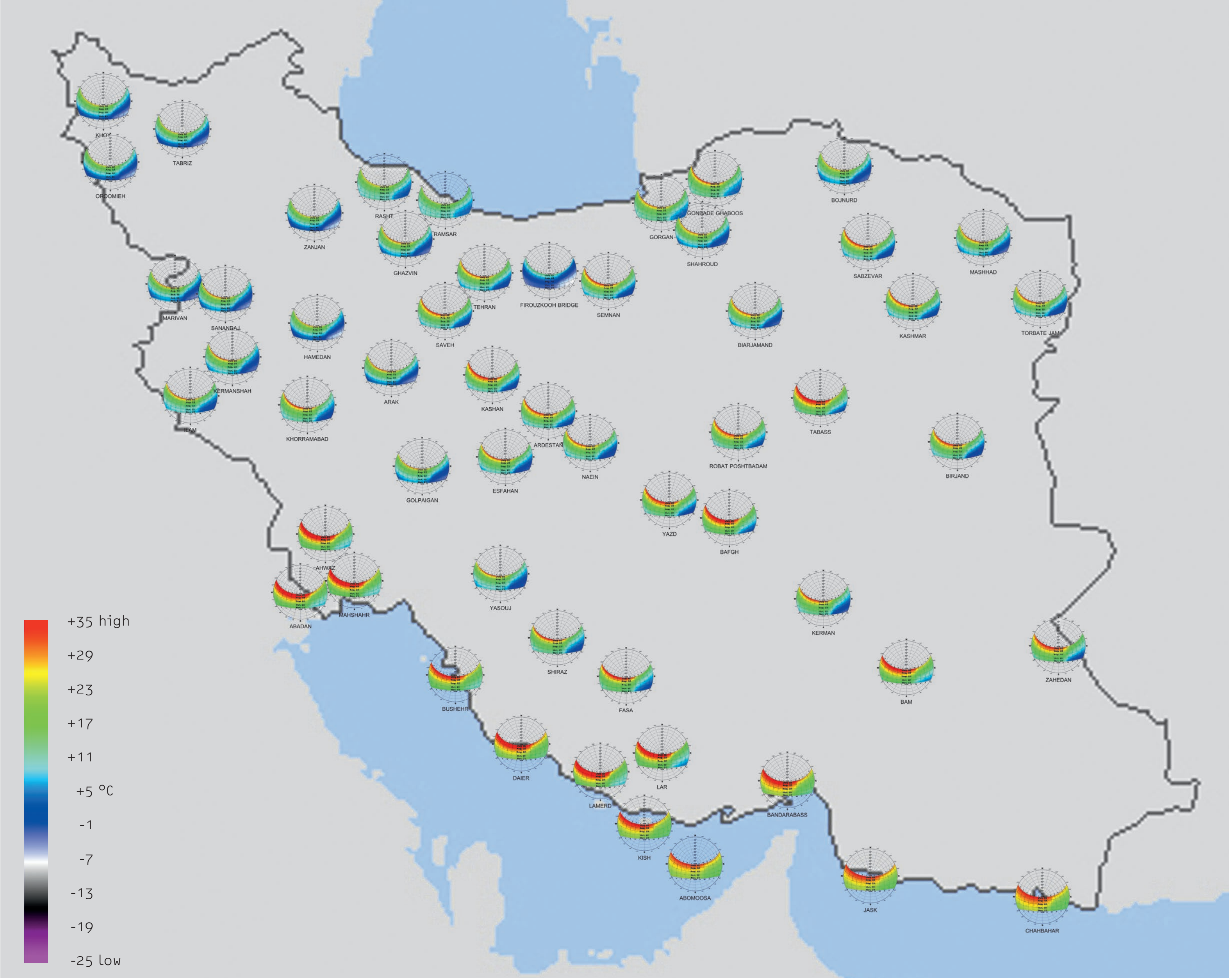
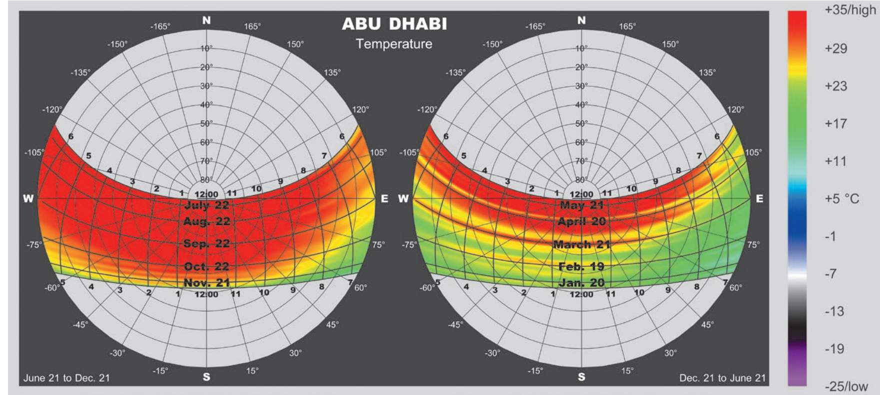
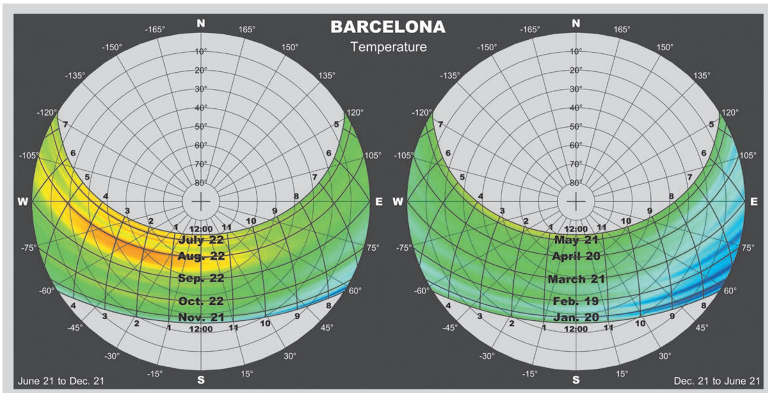
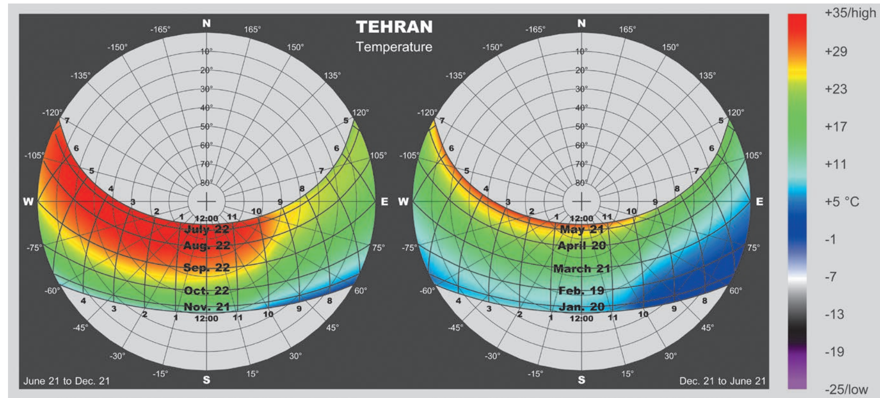


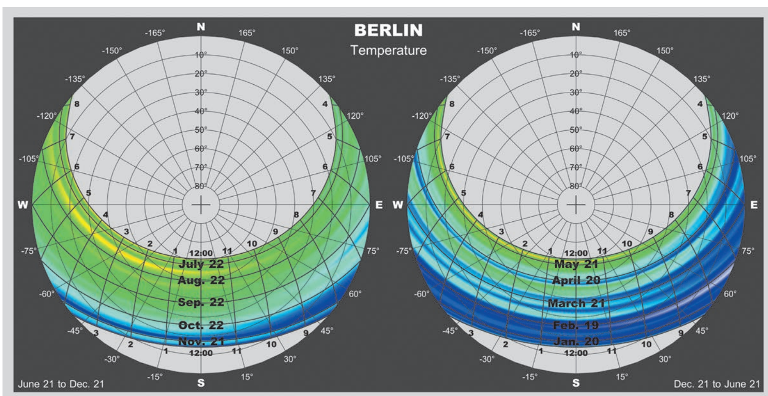
Fig. 57: Average hourly temperature in Iran (from 21 December to 21 June) based on long-term daily minimum and maximum temperature averages calculated by SOLARCHVISION

By plotting the hourly outdoor temperature on the sun path diagram for different months of the year, the pattern of temperature change is displayed for each location. The following diagrams illustrate the different situations in different cities around the world. As can be seen in all diagrams, the minimum daily temperature occurs around sunrise and the maximum temperature in the afternoon, which simply shows the effect of the sun on the change of temperature. These patterns for each particular location can help to determine when and where the sun enters a building and shines upon an open space. It is worth studying the complex dry climate of cities like Tehran where both hot and cold conditions occur during the day and in different months of the year. For instance in









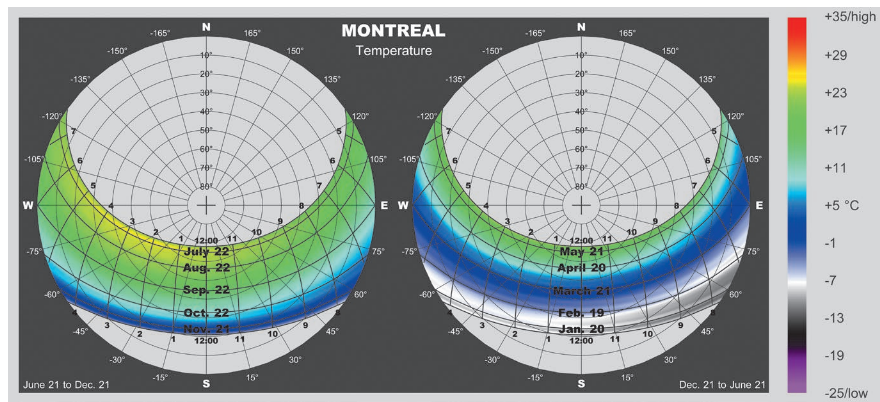


Fig. 58–62: SOLARCHVISION plots for average temperature patterns of Barcelona (TMY-USDE), Berlin (TMY-USDE), Abu Dhabi (TMY-USDE), Tehran (1953–2005, IRIMO) and Montréal (1953–2005, CWEEDS)

Tehran, although the sun has the same position in the sky on February 19 and October 22, it has different positive and negative effects in regard of the cold and warm conditions.

The ability of the human body to maintain an internal temperature of 37°C, in particular in the brain, despite the high and low outside temperatures, is called thermoregulation. In this respect, there are a number of systematic similarities between the human body and architecture.

1. Similar to the well-known role of a 37°C temperature for a healthy functioning of the body, an environment with a temperature of around 21°C should be maintained indoors when buildings are in use. The internal air temperature, however, differs according to different factors, including the building function.
2. The major role of blood circulation is to deliver energy and other matter to and from all parts of the body. A further critical aspect of blood circulation is to maintain a balance in temperature, in both cold and warm conditions. Modern mechanical and electrical systems apply a similar concept.
3. There are general similarities between the processes of heat production and heat loss in the human body and buildings, as well as the significant role of the human skin and the building envelope in protecting and adjusting the internal conditions. The different elements of the building façade, such as balconies, sun shading devices, trees, etc. in protecting the building, are similar to the functions of clothes, hats, umbrellas, etc. in protecting the human skin." (Samimi et al., 2009)

By studying these similarities as well as a variety of other organic systems within the environment, including animals and plants, helpful concepts can be found and developed not only to create and maintain internal comfort and improve the energy-saving performance but also to combat local and global challenges to mankind now and in future. Consequently, in a changing world, in addition to developing new materials and tools to improve the energy-efficiency of ordinary buildings, adaptation, hibernation, migration and many environmentally-friendly concepts to resist and adjust to different changing climates should be considered and applied within a green architectural design and sustainable development.

Without any doubt, one of the focal points here is how the concept of senses in the skin can influence the design, simulation and interaction of building skins in future. To better clarify this idea, it is necessary to mention that most simulation and measurement tools currently use the indoor conditions to determine whether the building envelope works properly or not; however, to achieve accurate results more items must be specified in detail, including, but not limited to, the mechanical and electrical systems and materials. But, in most cases, such detailed information is not available at the early stages of an architectural design. As a result, architects have to make lots of assumptions or omit this kind of analysis. On the other hand, if there is an issue concerning the performance of a building, it is not always easy to determine which item should be changed to create a more optimized solution. For example, the analysis or measurements in a building show high loads for cooling after 6.00 p.m. in summer. In this case, one may think that protecting the building skin from direct radiation during that particular period is necessary and may consider planting some trees in front of the west façade to improve the situation. However, after 6.00 p.m., the amount of direct solar radiation decreases significantly because the rays travel longer inside the atmosphere. The high cooling loads in the evening are most probably the result of exposure to high amounts of direct solar radiation between 10.00 a.m. and 4.00 p.m.; consequently a better solution should be found by providing more shading on the roof rather than trees in front of the west façade.

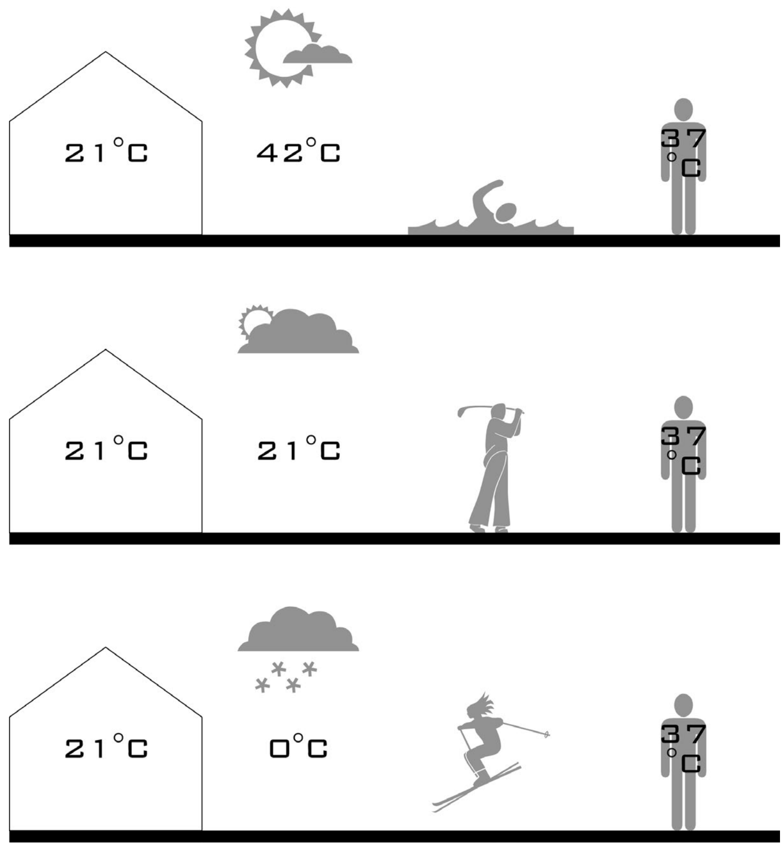
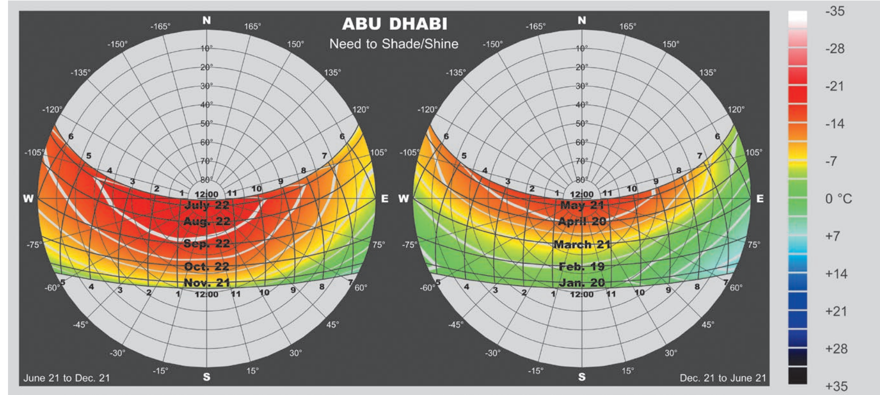


Fig. 63: Thermoregulation in the human body and architecture

One of the largest heat gains in buildings, depending on the geometry and the window surface area, is the external heat gain via the windows. Solar heat gain can have both a positive effect during the heating period and a negative effect during the cooling period. Generally, solar heat gain is required when the air temperature is lower than the lower boundary of the thermal comfort zone. Solar heat gain, in this case, can help to provide internal comfort without consuming energy for heating the building. But solar heat gain can also lead to overheating, for which extra cooling energy is then required to remove the unnecessary heat. This situation occurs mostly, and is extremely problematic, when the outdoor air temperature is higher than the lower boundary of the comfort zone. In this case, shading is required to minimize the solar heat gain.

Similar to the well-known concept of heating and cooling degree day, the pattern created based on the differences between the hourly outdoor



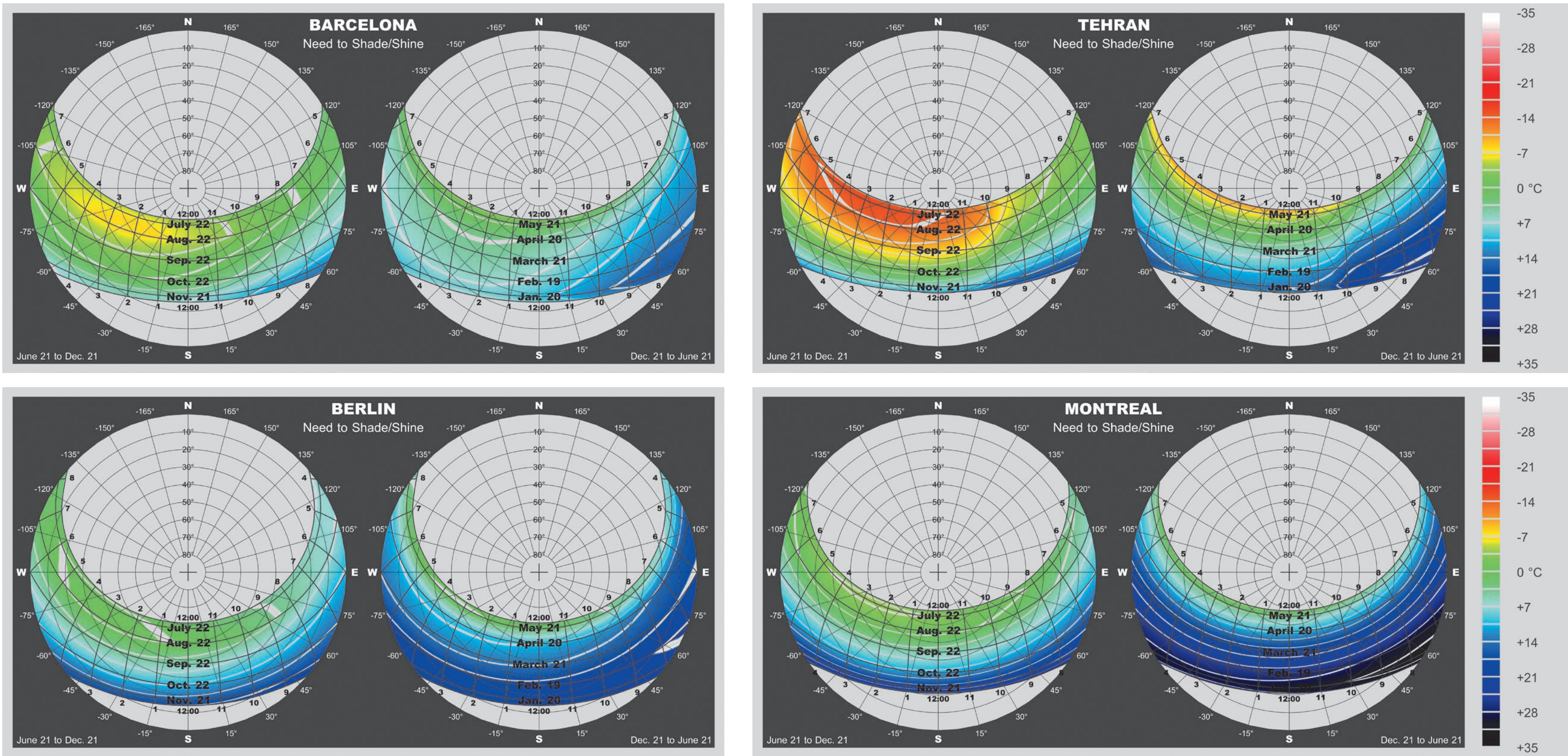


Fig. 64–68: SOLARCHVISION plots for Degree of Need to Shade/Shine patterns in Barcelona (TMY-USDE), Berlin (TMY-USDE), Abu Dhabi (TMY-USDE), Tehran (1953–2005, IRIMO) and Montréal (1953–2005, CWEEDS)

temperature and the required base temperature (21°C) is called Degree of Need to Shade/Shine and plotted for different cities as follows. By studying this pattern, it is possible to figure out, when the sun is at a certain position, and how much colder or warmer the weather is.

The difference between the outdoor temperature and the required base temperature (which is considered in this study as 21°C) can define how cold or hot the weather is. For instance, the difference between 51°C and 21°C is one and a half times the difference between 41°C and 21°C and three times the difference between 31°C and 21°C. In the same way, the difference between -9°C and 21°C is one and a half times the difference between 1°C and 21°C and three times the difference between 11°C and 21°C. On the other hand, slight differences between the upper and lower temperature limits of the comfort zone (18°C and 24°C) are presented by small values of a ±3°C distance to 21°C.

The patterns of Degree of Need to Shade/Shine illustrate different areas which require more accurate considerations, namely in regard to the energy of the sun. For example, if the outdoor air temperature is 36°C, solar energy is not required to warm the building skin and the windows, in particular, in order to maintain comfortable internal conditions. On a sunny day with a temperature of 36°C, people also seek shade in outdoor spaces to be protected from the sun. On the other hand, if the temperature is 51°C, for people outside, being in the shade and, for people inside, the building skin is considered as being twice as important, especially if the other parameters, such as humidity, wind speed and solar radiation, remain the same.

However, the base temperature can be changed in regard to other parameters, e.g. time (heating/cooling period), internal heat gains, regional habits, etc. As is mentioned above, in this study, the required base temperature is considered a constant value for a number of reasons. One of the main ones is about creating basic, comparable information for different locations and projects types (namely residential buildings).

The outdoor temperature can play a central role in connection with the definition and application of the parameter Degree of Need to Shade/Shine in buildings because natural ventilation can be used to cool buildings in case of overheating. At an outside temperature of 15°C, for instance, cool fresh air can be used to balance the temperature of overheated interior areas. The same idea may also be used if the inside temperature drops below that of the comfort zone when the outside weather is warm. In such cases, a higher temperature set up of cooling systems is an environmentally friendly solution as the amount of energy and cost spent on active cooling, as well as the direct negative environmental effects, including pollution, heat island effect and global warming, is significant. Instead of direct and indirect utilizations of the sun for cooling the interiors, many buildings today use electricity from the grid. This leads to huge peaks in the city's electrical grid. Instead the design and optimization of building envelopes and orientation could be based on the pattern Degree of Need to Shade/Shine, in addition to solar radiation patterns, to reduce and balance the extreme values of these peaks. These aspects will be discussed in greater detail later.

As the solar heat gain can effectively influence both the heating and cooling energy demand of the building, the definition of need to shade or shine and the implementation of this feature in the architectural and urban design, can lead to climate responsive architecture. It is necessary to mention that the Degree of Need to Shade/Shine is only defined in relation with the thermal comfort effect of solar radiation and is not related to daylighting subjects.

6 Positive and Negative Effects of the Sun

In architecture and the relationship with the sun, there have always been questions concerning the form, orientation and elongation of buildings, the amount of openings in each direction and the layout of building mass. These questions either relate to passive or active strategies that can be applied by planners and architects in urban planning and building design. In an active strategy, the form and orientation should be designed in such a way that the building façades receive a greater amount of energy from the sun. Whereas this energy can be used directly in colder periods, it can also be used for cooling systems during hot periods. Thus, in terms of active strategies, the sun should always be considered a positive source of energy everywhere. However, in a passive approach, the sun has two different effects: the favorable effect, which appears in cold periods, and the unfavorable effect, which appears in hot times. According to the conditions of the location, the favorable and unfavorable aspects of the sun differ from place to place.

The positive or negative effect of solar radiation at each moment depends on two variable parameters: the amount of solar radiation and the difference between outdoor temperature and desired indoor temperature (e.g. 21°C) as defined by the Degree of Need to Shade/Shine (Samimi and Tahbaz, 2007). Consequently by multiplying the hourly amount of the direct solar beam radiation with the degree of Need to Shade/Shine in each hour during different months of the year, the effect of the direct beam radiation can be calculated using the SOLARCHVISION computer program. Similar calculations can be performed for diffuse radiation as well. The following graph illustrates the positive and negative effects of direct solar radiation in relation to cold/warm weather during half an annual cycle for the city of Hashtgerd (case study of the Young Cities research project), which is located 65 km west of Tehran.

As is presented by the results of the diagram, the most undesirable effect of the sun occurs when both the temperature and the solar radiation are high. As plotted in red, the most unfavorable effects usually occur on this site between 10 a.m. and 5 p.m. from June to September. The negative effect of the sun in summer is not immediately after sunrise or in the last hours before sunset, as the amount of direct radiation decreases significantly when the altitude of the sun is 15° or lower. The results also highlight the times and the position of the sun in which the positive impact of the sun is greatest. Once again, when the altitude of the sun is 15° or lower, the amount of direct radiation decreases significantly as the rays have to go through more layers of the atmosphere. Therefore, despite the low temperatures, which generally occur at the time of sunrise, the positive effect of the sun reaches its maximum a few hours after sunrise, when the sun is at a higher altitude, but the temperature is still low.

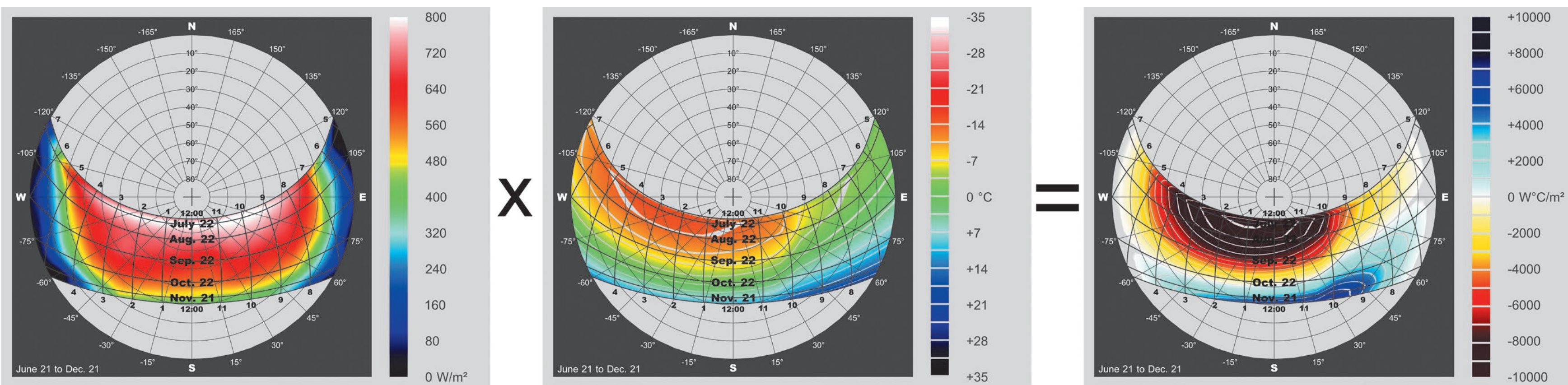


Fig. 69: Calculation of the hourly +/- effects of direct solar radiation for Hashtgerd between 21 June and 21 December from the multiplication of patterns concerning the hourly direct radiation and the hourly need to Shade/Shine

Fig. 70: Schematic diagram to show the relation between the altitude angle of the sun and the distance passed through the earth's atmosphere

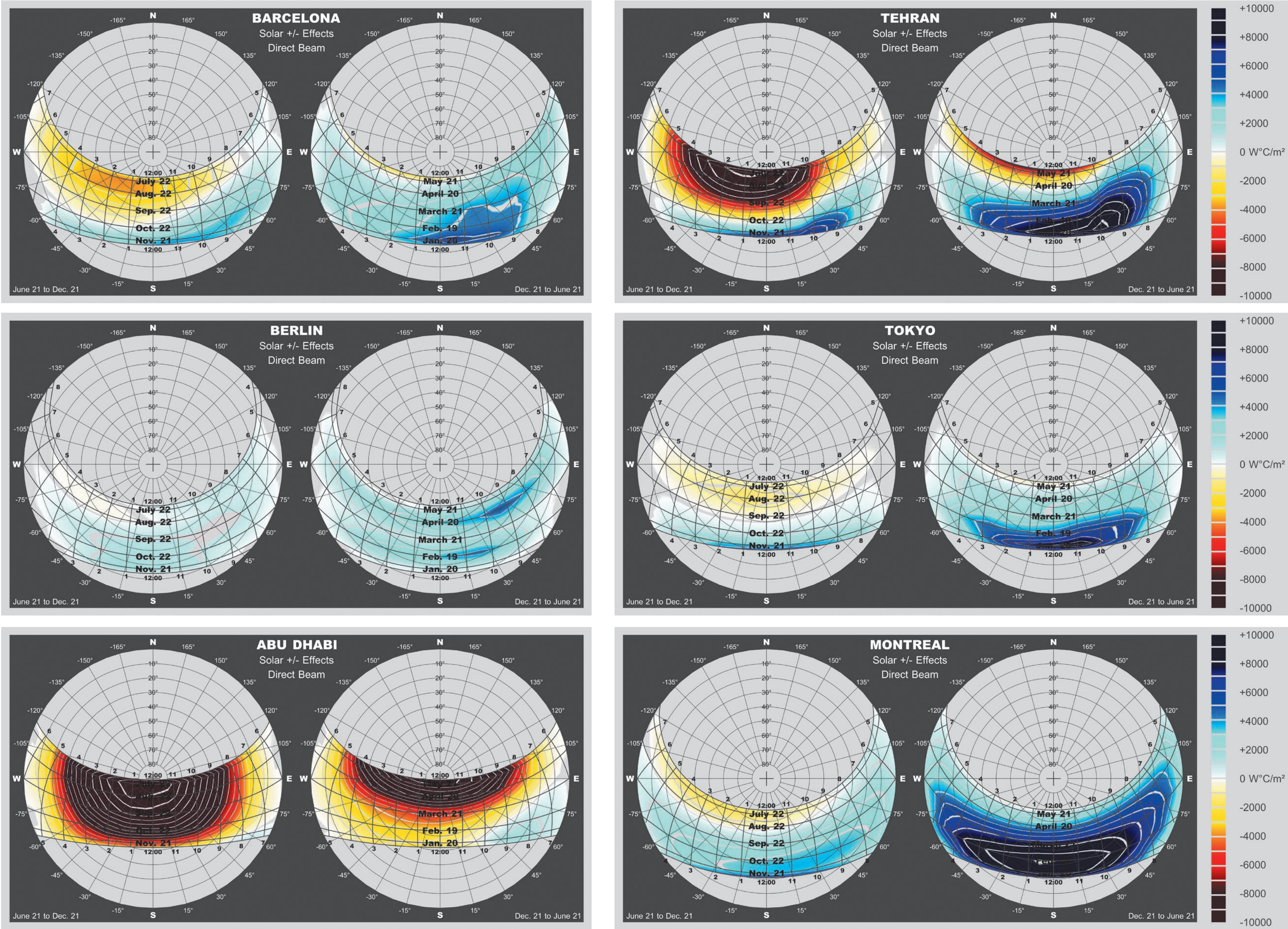


Fig. 71–76: SOLARCHVISION plots for general patterns of positive and negative effects of direct beam radiation in Barcelona (TMY-USDE), Berlin (TMY-USDE), Abu Dhabi (TMY-USDE), Tokyo (TMY-USDE), Tehran (1953–2005, IRIMO) and Montréal (1953–2005, CWEEDS)

As the temperature changes and the solar radiation levels are not the same in the two cycles of the year, two different diagrams are essential to display the characteristics of the sun in each location, as is presented on the following pages: one from 21 June to 21 December (left side) and the other one for the period between 21 December and 21 June (right side).

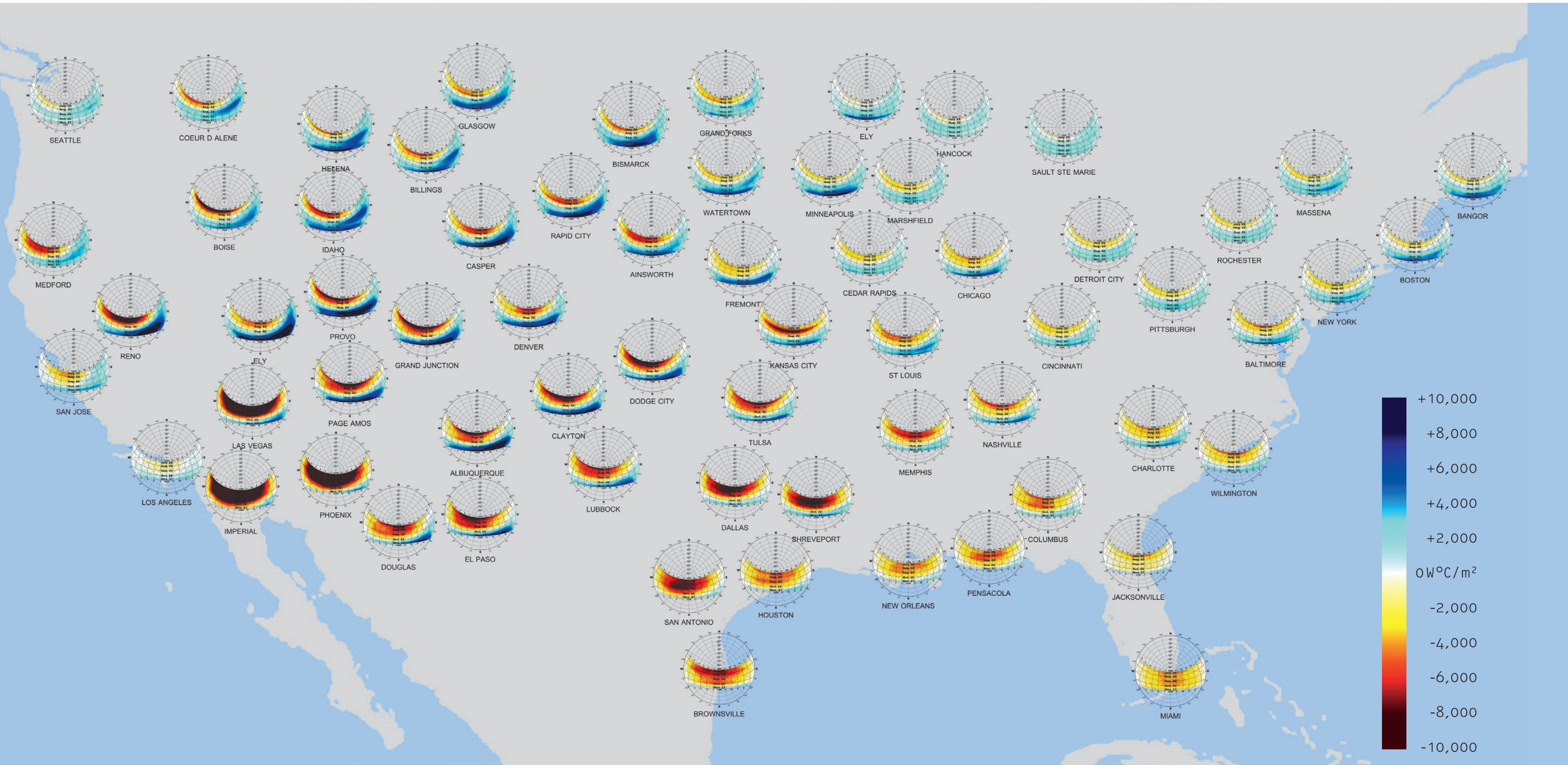


Fig. 77: Average hourly positive and negative effects of direct solar radiation from June 21 to December 21 in the USA

Based on the Typical Meteorological Year data of U.S. Department of Energy, the general positive and negative effects of the sun are plotted using SOLARCHVISION for different cities around the world.

The following diagram illustrates the positive and negative effects of direct solar beam radiation in different cities of the USA between 21 June and 21 December using Typical Meteorological Year data. According to the diagram, both the positive and negative effects of the sun are considerable in most western and central areas during this period.

It is interesting that the climate in Los Angeles is quite so moderate being so close to Las Vegas with its extreme conditions.

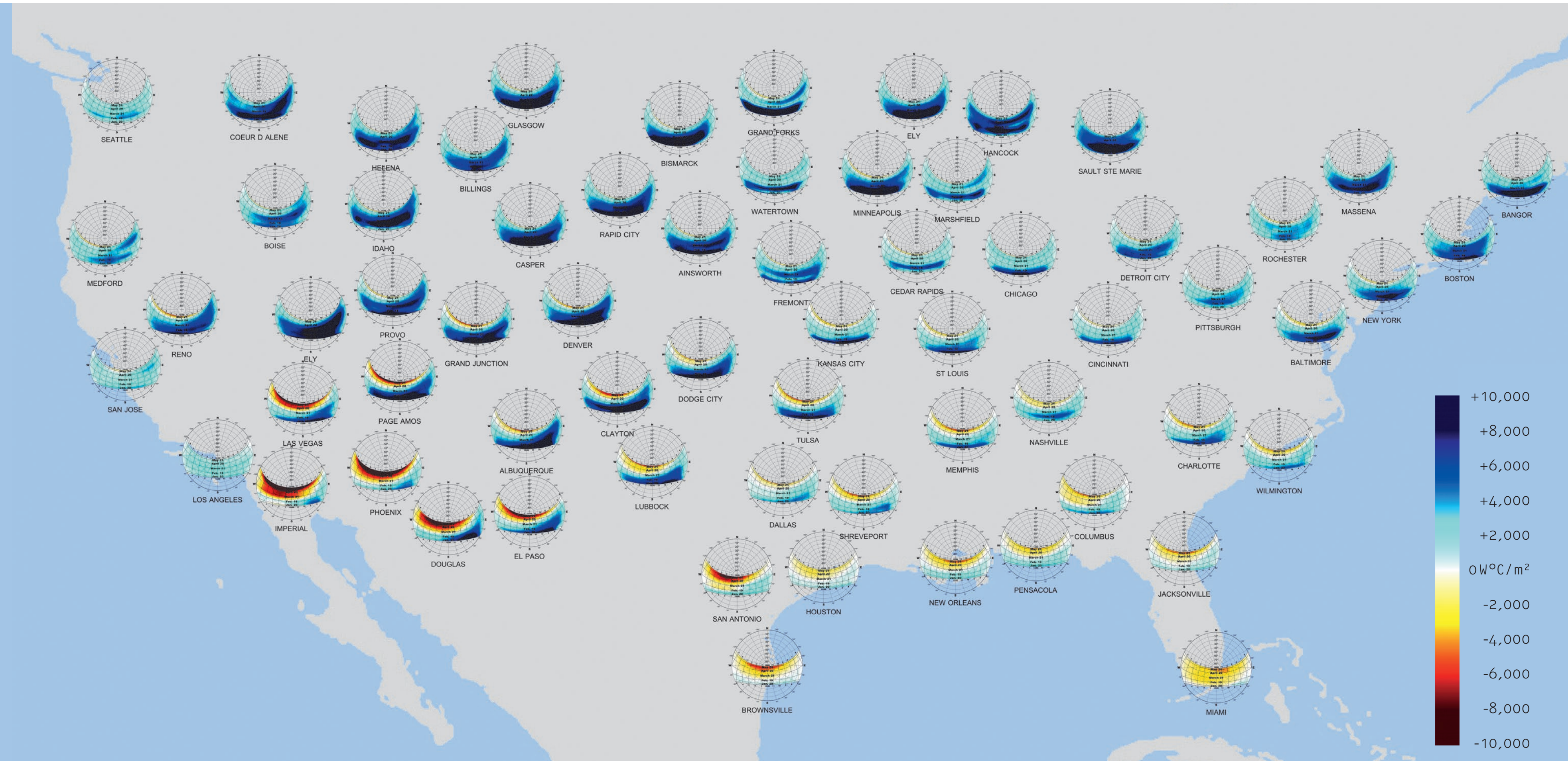


Fig. 78: Average hourly positive and negative effects of direct solar radiation from December 21 to June 21 in the USA

A similar diagram for the period of winter and spring (21 December and 21 June) shows that both the positive and negative effects of the sun are more intensive in most western and central parts of the USA even though the western coastal cities, like Los Angeles, Seattle and San Jose, have a more moderate climate.

Similar moderate situations occur in the southern parts of the eastern coast areas. The positive effect of the sun in the northern parts of the east coast is the result of cold winters and sunny conditions.

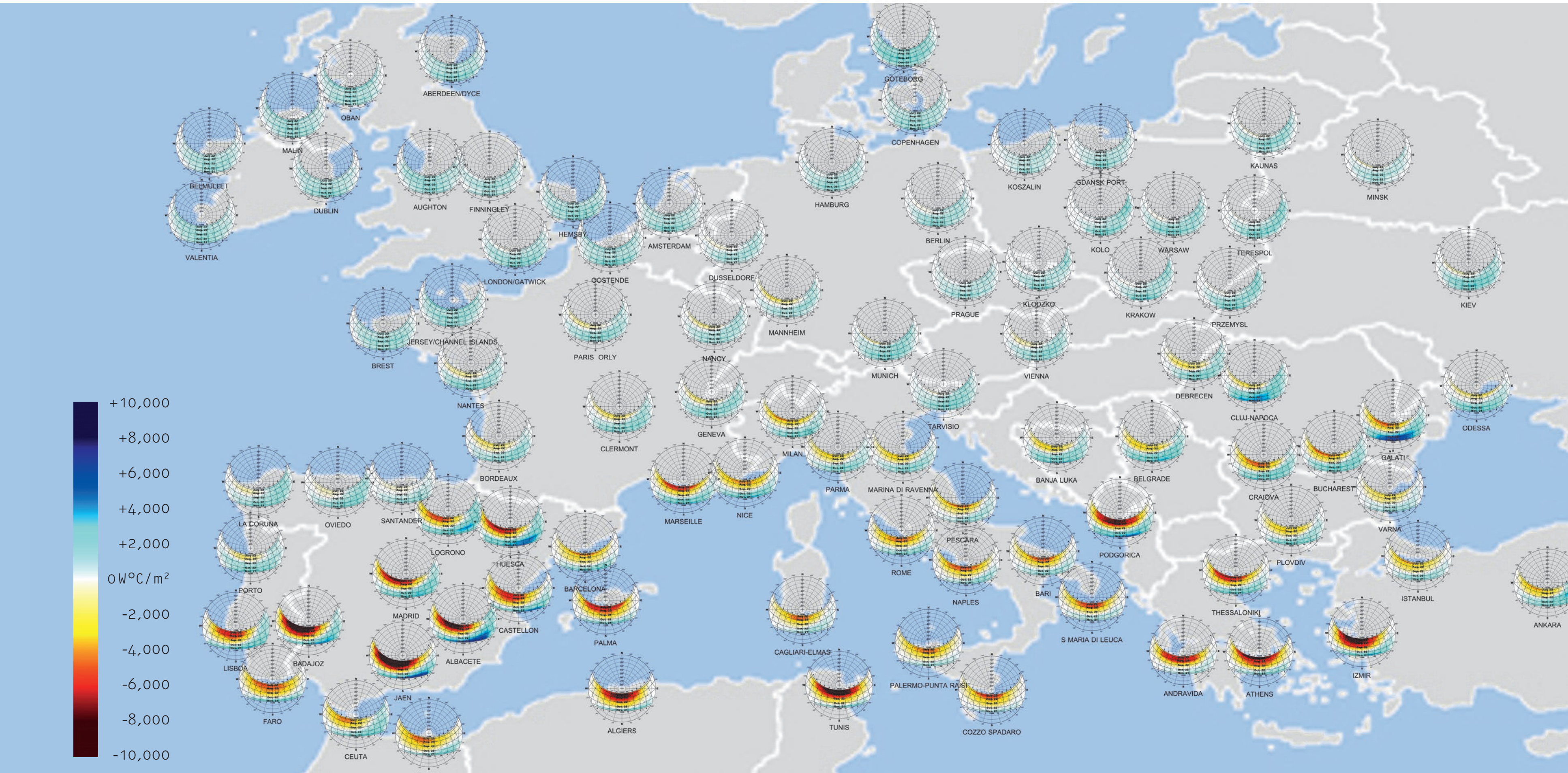


Fig. 79: Average hourly positive and negative effects of direct solar radiation from June 21 to December 21 in Europe

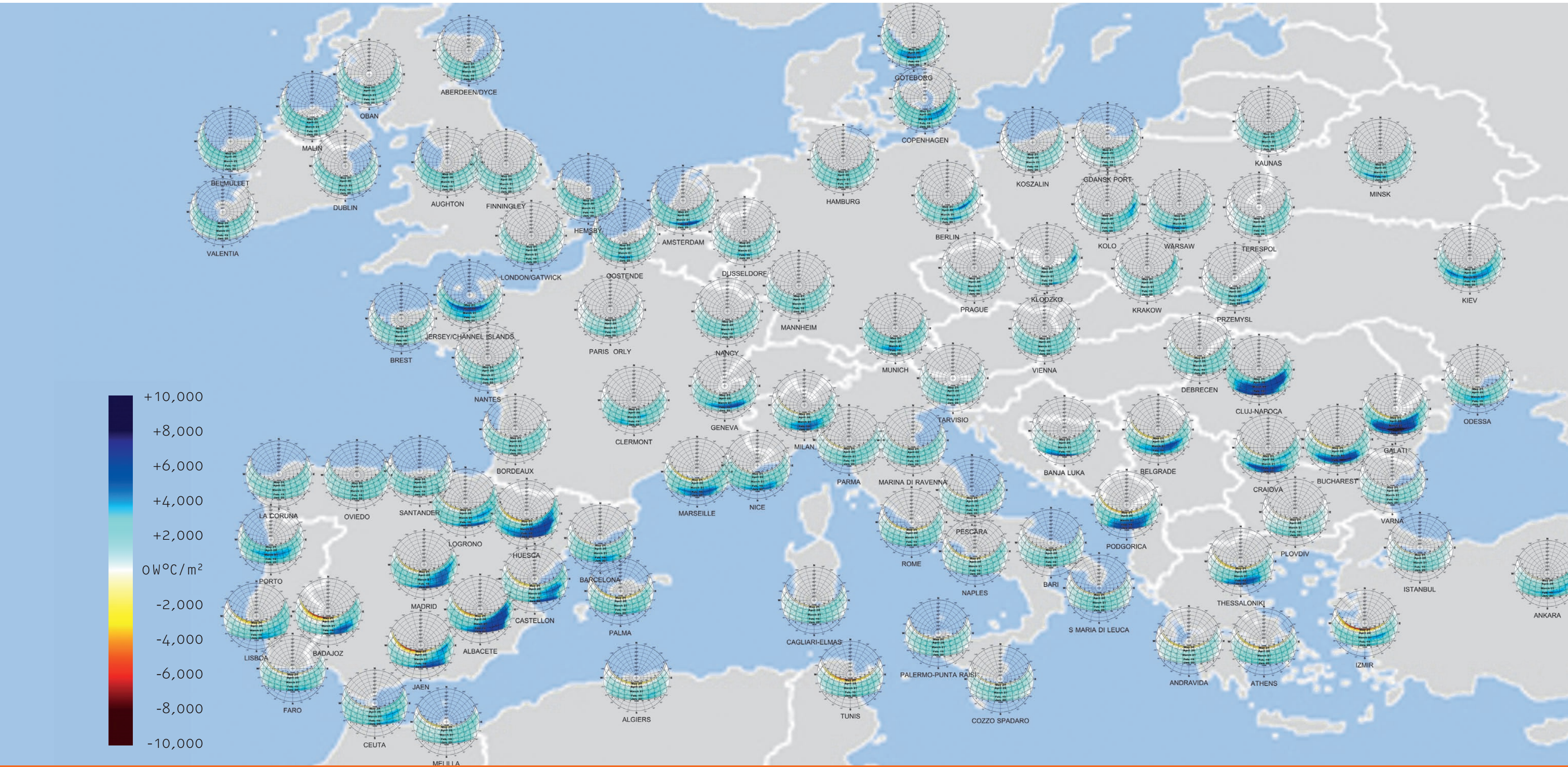


Fig. 80: Average hourly positive and negative effects of direct solar radiation from December 21 to June 21 in Europe

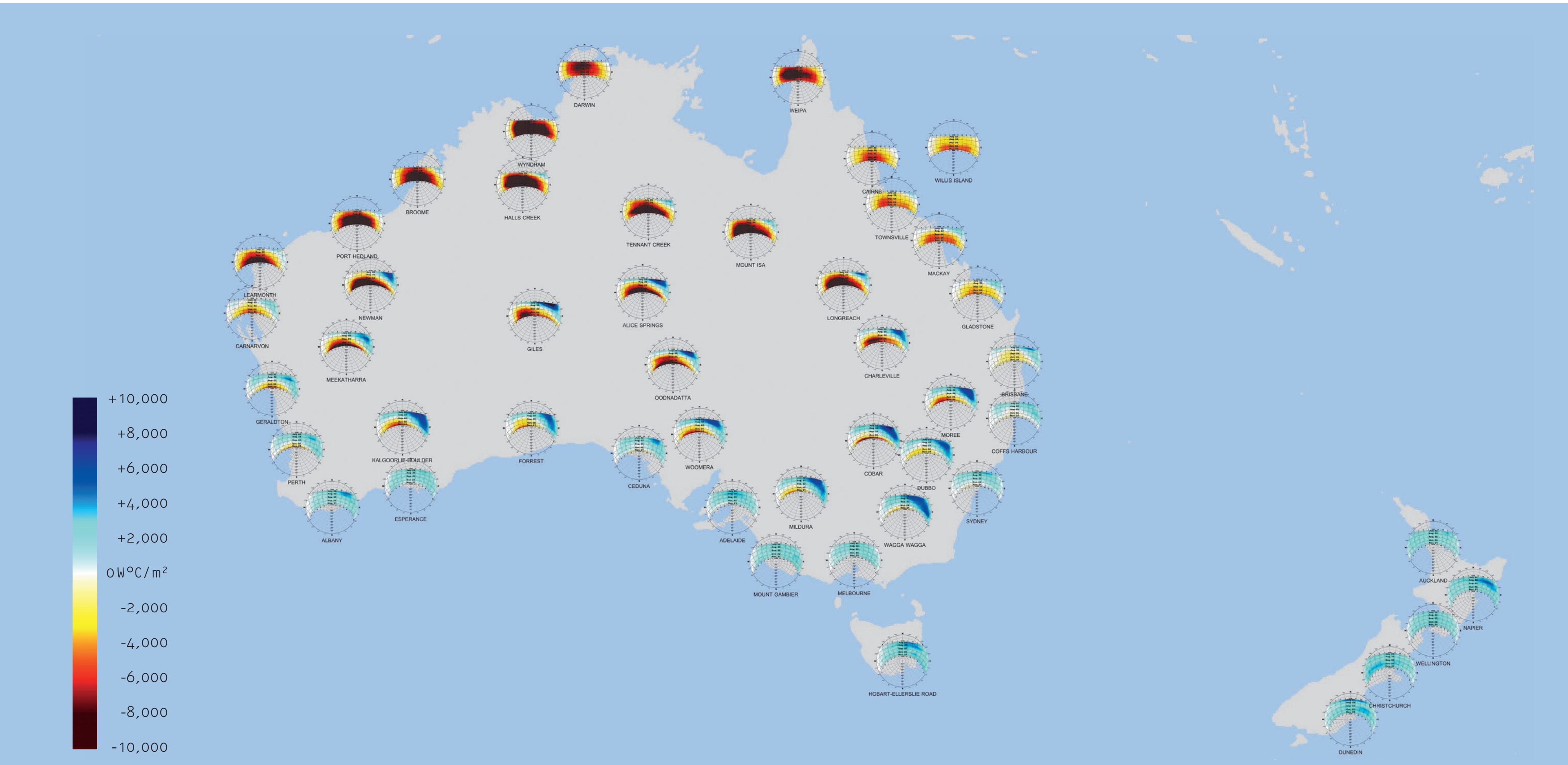


Fig. 81: Average hourly positive and negative effects of direct solar radiation from June 21 to December 21 in Australia

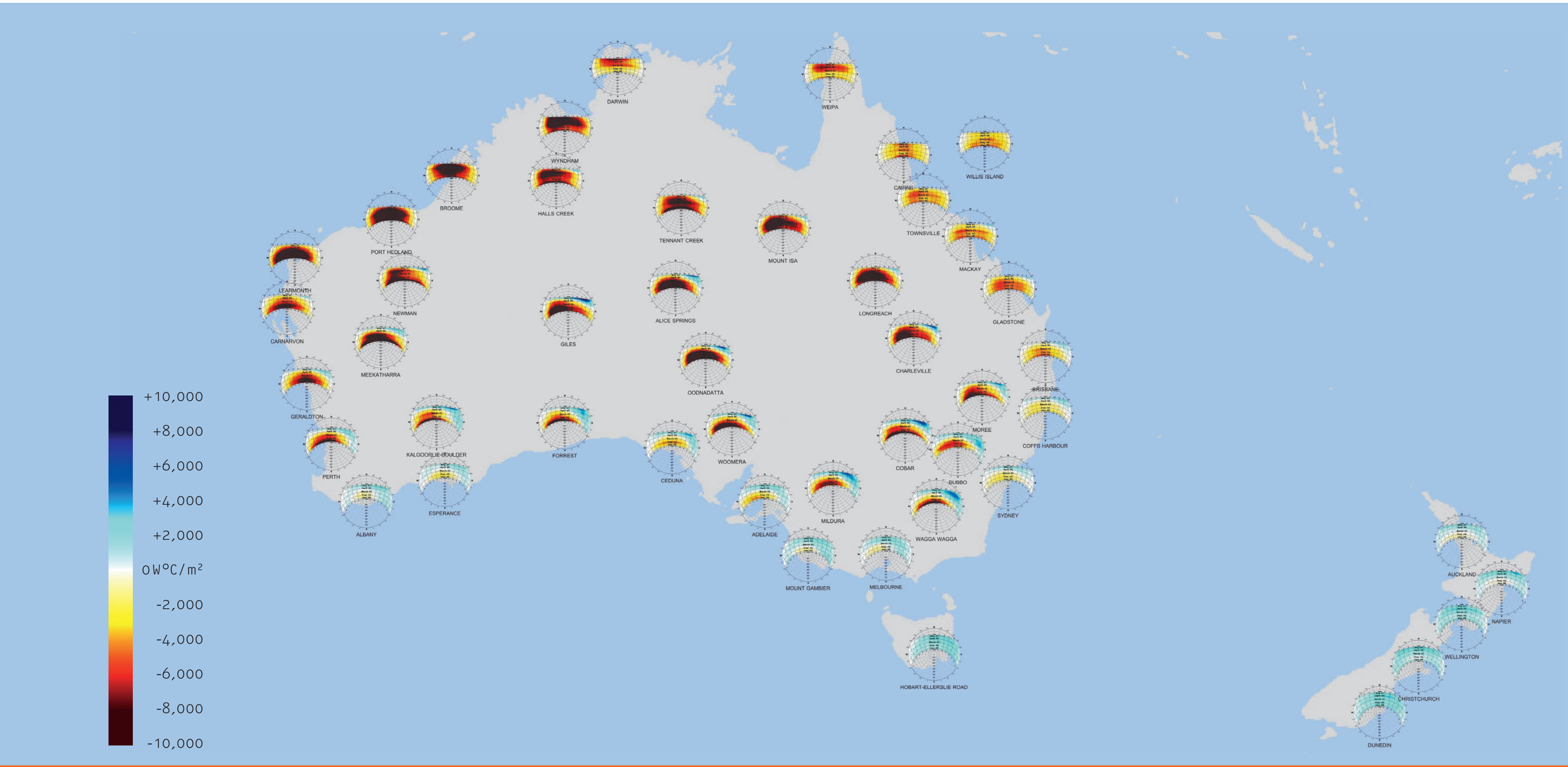


Fig. 82: Average hourly positive and negative effects of direct solar radiation from December 21 to June 21 in Australia

Fig. 83: Average hourly positive and negative effects of direct solar radiation from June 21 to December 21 in East Asia (China, India, Japan, etc.)

The two following diagrams present the situation of the positive and negative effects of direct solar radiation in Asia, which is performed by SOLARCHVISION based on the Typical Meteorological Year data. A comparison between the two diagrams simply shows bolder effects of the sun in this populated part of the world in winter and spring. The reason is that most of these areas have rainy seasons during summer and autumn. In some of these areas, including some parts of India, the temperature is high in summer (+42°C for instance). The negative effect of direct solar radiation is not very high as the amount of direct solar radiation is low thanks to the cloudy and rainy conditions.

Fig. 84: Average hourly positive and negative effects of direct solar radiation from December 21 to June 21 in East Asia (China, India, Japan, etc.)

Interestingly and contrary to first thoughts, in the southern parts of Asia, in particular in India, the negative effects of the sun during winter are extremely high due to both the sunny days and high temperatures (+35°C for instance). These aspects should be considered carefully in architectural design and urban planning.

Fig. 85: Average hourly positive and negative effects of direct solar radiation from June 21 to December 21 in Iran

Fig. 86: Average hourly positive and negative effects of direct solar radiation from December 21 to June 21 in Iran

II
The Sun, Climate and Architecture

Earth is the only known appropriate place for all living matter, from a cell to a variety of plants and animals, because of its specific conditions, including, but not limited, to having water, air and a good distance to the sun as well as its rotation around its own axis, which is responsible for the rhythm of day and night. The human, which is a weak-body creature, is on earth at the most appropriate time. With the power to think, humans have gradually come to terms with the unfavorable aspects of the surrounding environment. The developments from clothing and primitive shelters to what is today called "architecture" are essential to provide human safety, health and comfort.

The sun as one of the important actors in establishing different climates on earth, and with its favorable and unfavorable effects, has presented the human race with several important challenges. Thousands of years after humans got down from the trees and out of the caves, they migrated to find more favorable conditions or settled down in areas with the help of agriculture. In some countries with extreme hot and cold conditions during the year, people live in fixed housing, but movement still takes place between summer and winter parts of their houses. Similar to other circumstances around the world, in traditional Persian architecture, passive concepts, as well as the formation of space around a central courtyard, have always created favorable conditions for some parts of the interior, and that is why there are specific names for the rooms in relation to summer and winter. In addition to the architectural form of courtyard houses, a sound location of pools and trees in the outdoor area, as well as the utilization of wind-catchers, should be studied in their function of providing comfort. In fact, an integrated architectural system like this was used not only to build a number of villages in a desert with natural and recyclable material of adobe but also to plant the environment thanks to the technology of Qanats, which were responsible for providing water from far distances.

Fig. 87: Bam before 2003 earthquake (Damoun Vahabi-Moghaddam)

In such a fabric, where all the houses look inside to their courtyards, everyone can observe the horizon as well as the blue sky from sunset to sunrise and enjoy going to sleep while looking at the moon and stars on the roofs. But things have changed from the past, and one needs to look carefully to rediscover things that contain real values. (Rashidzadeh et al., 2002) On the other hand, human interference in the environment's cycles, as has been the case in previous decades too, has grown rapidly and become more intensive so that today it is not possible to tell whether life on earth will be able to continue with the pollution and the wasteful use of resources being as high as they are today. As small particles of the universe, we must therefore learn to respect and protect all members of the natural environment whether we are a client, a planner, a builder or a user.

According to Task 41 (Solar Energy and Architecture) of the Solar Heating & Cooling Programme at the International Energy Agency, "Existing buildings account for over 40% of the world's total primary energy use and 24% of greenhouse gas emissions" (Maria Wall et al., 2008)

To improve this situation, the role of the sun should be the focus of our attention throughout the development of the design, construction and operation of new generation architecture and urban planning. Therefore, as no building can stand without a proper structure, the lifecycle of every building and city should be considered according to the structural role of the sun with its powerful and varied effects. This is essential not only for the pure and unlimited energy provided by the sun but also for other aspects involving the history of human life and its future.

In addition to the quantitative factors, energy efficiency and natural daylighting, which are frequently mentioned thanks to green and sustainable development approaches, a solar approach can lead to other qualities for the benefit of the small and large-scale living spaces, whether indoors or outdoors by means of a climatic responsive design.

Thus, the state of art in architecture is to adjust both internal and external living spaces in a coordinated and balanced way. Meanwhile, one of the major challenges in architectural/urban design arises when the designer separates the indoor space from the outside by forming the skin boundary to define a specific relation between the two. (Samimi et al., 2012)

On the other hand, in each location, the sun has different positive and negative effects over time: the favorable effect of the sun, which appears in cold periods, and the unfavorable effect, which appears in hot periods. Therefore, one of the central challenges of design in architectural and building skin scales is to shape the building volume as well as its skin so that the envelope, and in particular the fenestration, receive more solar energy during the heating period. During hot periods, in contrast, they should be protected properly from the solar radiation. Instead, the energy can be used intelligently directly or indirectly with active and passive cooling systems. (Samimi, 2007)

"In terms of sun and climate, which orientation and form is best for a building?" This is one of the most frequently asked questions at the beginning of every architectural and urban design process. However, in answering this question, the main idea of which has not been changed much from what Socrates said in 4th century BC: "Do you admit that any one purposing to build a perfect house will plan to make it at once as pleasant and as useful to live in as possible? It is pleasant to have one's house cool in summer and warm in winter, is it not? Now, supposing a house to have a southern aspect, sunshine during winter will steal in under the verandah, but in summer, when the sun traverses a path right over our heads, the roof will afford an agreeable shade, will it not? If, then, such an arrangement is desirable, the southern side of a house should be built higher to catch the rays of the winter sun, and the northern side lower to prevent the cold winds finding ingress; in a word, it is reasonable to suppose that the pleasantest and most beautiful dwelling place will be one in which the owner can at all seasons of the year find the pleasantest retreat, and stow away his goods with the greatest security." (Xenophon, 1979)

But what if we copy perfect houses and paste them beside each other; do we get a perfect city? What we want to do here is to underline the complexity of an optimal architectural design from an integrated as well as an urban design point of view. Another question which may help is about the changes which should be made to our copied instances of perfect houses during the process of pasting them together to form a new environment with different conditions and demands.

New technologies and materials are changing the figure of buildings; and as is discussed in the context of the "building skin", these changes are extremely effective to advance the performance of the building envelope by increasing the benefits from the favorable aspects of the environment (e.g. daylighting and pure energy from the sun) as well as by blocking the negative ones out (e.g. hot and cold weather). As a result, nowadays, it is not difficult and even quite fashionable for the architects and their clients to think about interactive skins for their buildings to respond intelligently and look intelligent. An architect who successfully maximizes the benefits for his or her client has hardly thought about the negative impacts of the buildings on the urban fabric. In fact the architect is only responsible up to the boundary of the client's site and these effects must be studied earlier in urban planning phases. Therefore, as increasing benefits for each single building can decrease the benefits of others, there are still serious questions about creating or modifying building volumes inside a neighborhood to achieve a proper relationship among each other as well as the environment, which needs more attention and deeper studies. However, in many developing countries with an unbelievable need for new constructions, the solutions to these critical basic questions have to be answered in a very limited time and budget.

Because ordinary buildings in the urban fabric are considered fixed objects, the urban design should be intelligent enough to provide comfort both inside and outside throughout the whole cycle of a year. The significance and complexity of improving the building's characteristics, including orientation and the proportions of the building mass, to meet the scale of the neighborhood and the city, increases immensely if we take both the comfort factors outdoors and indoors into consideration in the design. (Samimi et al., 2008)

Providing the comfort inside a building, using a heating and cooling system, has a direct impact on the building's energy demand and, hence, the energy costs paid by the occupants. However, in comparison with outdoor comfort, the internal comfort is generally considered to be the

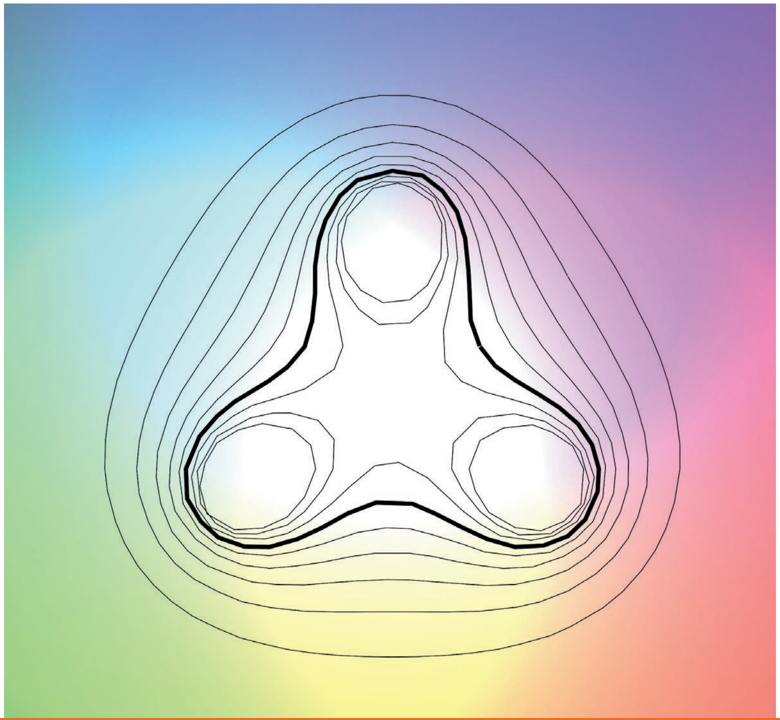


Fig. 88: Multi-layer optimization (for 3 factors)

more important factor in building simulations because of its direct link to a number of global effects, such as global warming, pollution and limitation of energy resources. The issues concerned with the outdoor space, on the other hand, are more related to health and safety, rather than energy and money. Thus, even though the idea of orientating long rows of building mass towards the south has become established to achieve maximum solar radiation in winter and minimize solar heat gain in summer, the result is that uncomfortable areas are developed between the building blocks (i.e. paths and courtyards), which are subject to long periods of shade in winter as well as long periods of high radiation in summer. Although these negative effects could be corrected by providing suitable strategies, such as the application of shading devices, reflectors, planting, etc., different and more enhanced solutions could be achieved by a better integration and distribution of indoor and outdoor spaces within the design. (Samimi et al., 2011)

As the optimization of a problem in regard to one parameter can result in the deterioration of other dimensions, the result of simplified optimizations should not be generalized for all cases. In other words, to find the optimum result, one should generally look at a wide range of maximum points and not a single maximum. (Figure 88)

Fig. 89: Spherical structure with fewer elements in comparison to geodesic, diameter = 4.5 m, weight: 180 kg, "Hybrid Globe" interactive installation at Scotiabank Nuit-Blanche Toronto, 2013, Arthur Wrigglesworth, Mohammad Mehdi Ghiyaei, Mojtaba Samimi

In the same way, solar-climatic optimizations in architecture and urban planning should result from considering and analyzing different alternatives. From this point of view, the most appropriate alternative is the one which responds, in an optimum way, to all requirements by using "less" (e.g. less cost, less energy, less material, less weight, etc.). To achieve such a design, all aspects within architecture, and in particular its interaction with the climate, should be taken to heart and implemented conscientiously by the architect or planner. The aim of the SOLARCHVISION studies is therefore to introduce a brand new vision for discovering the relation between sun and architecture by:

1. producing basic information design guidelines based on solar-climatic data
2. design, evaluation and modification of different alternatives for building elements in a variety of scales (ranging from a neighborhood to shading devices) from the point of view of the sun and its local effects in regard to climate.

Based on basic information provided in the previous parts and in regard to what is discussed here, solar radiation and its effects on different surface orientations and inclinations will be presented for Tehran and other climates of Iran in the following parts of this book. Having two active and passive strategies in mind, the method as well as the results of basic SOLARCHVISION analysis will be discussed in connection with past, current and future challenges.

In art and architecture, light and shadow are essential aspects. Unlike an installation in Nuit Blanche, in which all the interaction takes place from sunset to sunrise, the sun has an important role in shining on different geometries from sunrise to sunset. In the words of Le Corbusier "Architecture is the masterly, correct and magnificent play of masses brought together in light." (Le Corbusier, 1923)

In addition to the visual aspects of daylight, which enable us to see things as well as architectural form, the energy of the sun received by different building surfaces and in particular the openings in the building envelope (e.g. windows, solariums, balconies, etc.) should be studied with great attention. Concerning the role of the building skin as a solar and climatic response, the general building form and the number and size of openings, as well as the depth of the shading element in each orientation, should be optimized in unison. In this respect, each surface in a geometric shape has its particular position, and, only by studying and analyzing the situation, is it possible for an architectural concept to become intelligent enough or to interact and deform for the improvement of internal and external aspects (e.g. visual, climatic, etc.). As an example, in Figure 90, each surface in a spherical polyhedron can be developed parametrically or designed differently to achieve a suitable amount of open and closed areas; however, as we have found, it can also be built of 30 equally plane lozenges, thanks to the magical inspiration of M.C. Escher.

Further studies using SOLARCHVISION can help to provide the analysis of the solar and climatic response at a building skin level. On the other hand, and as we will discuss later, the production of energy with the building skin is another factor which can definitely affect and influence the future architectural concepts of small buildings as well as orientations and approaches in urban planning to combat local and global challenges.

Taking the example of Tehran in this section, the solar radiation and its effects on different surface orientations and inclinations have been studied. As is discussed in the first chapter of this book, the amount of direct beam solar radiation changes over time in relation to the position of the sun in the sky and the local atmospheric situation (namely in connection with humidity and clouds). The average pattern of direct solar radiation for the city of Tehran, as is illustrated in Figure 91, shows these changes in two half-cycles of the year: one from 21 June to 21 December, which is located on the left; and the other one from 21 December to 21 June on the right. In addition to this, and according to the definition of the degree of need to shade/shine, the general temperature pattern in each location, in this case in Tehran, can change the effects of the sun for several hours of the day in different months from a positive and favorable effect in cold periods to a negative and unfavorable effect in hot periods. Figure 94 (upper right) presents these general positive effects for the city of Tehran. As can be seen in this Figure, the warm and cold conditions with high amounts of direct solar radiation can lead to the extreme amounts of negative and positive effects occurring at different hours and days than is, for example, the case for the maximum points in the model of the direct beam radiation as presented in Figure 91 (upper left).

On the other hand, the time and the date of these extreme points, as well as the amounts, can be affected significantly by the orientation and inclination of each surface of building skin.

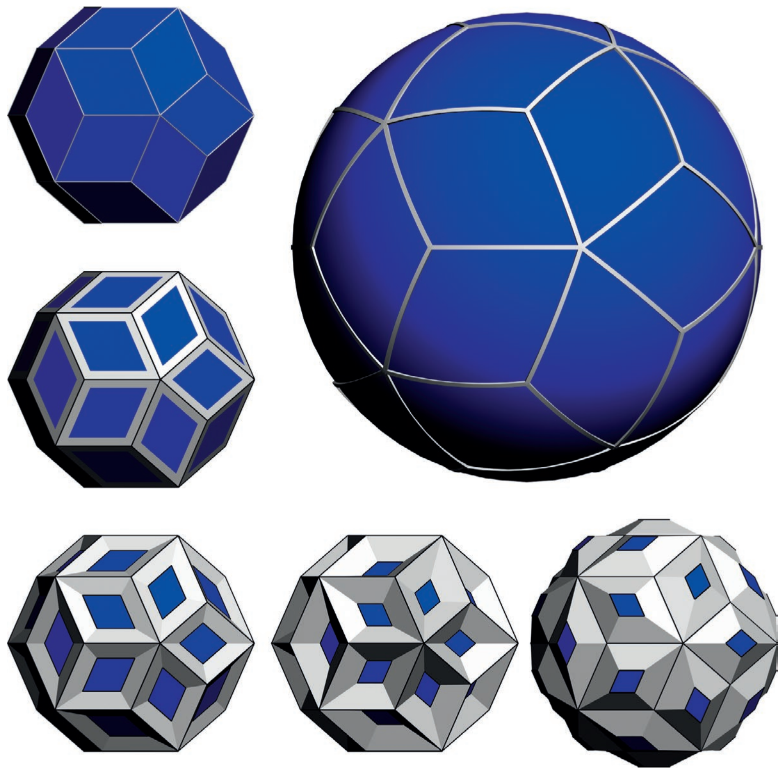


Fig. 90: Skin design variations for the new generation of spherical structures with a minimum number of element types (n=1), M. Samimi and M. M. Ghiyaei, R&D project of spherical structures with minimum element types, 2011–2013

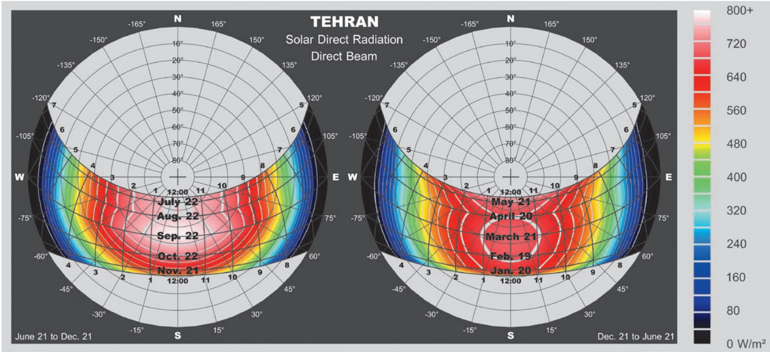


Fig. 91

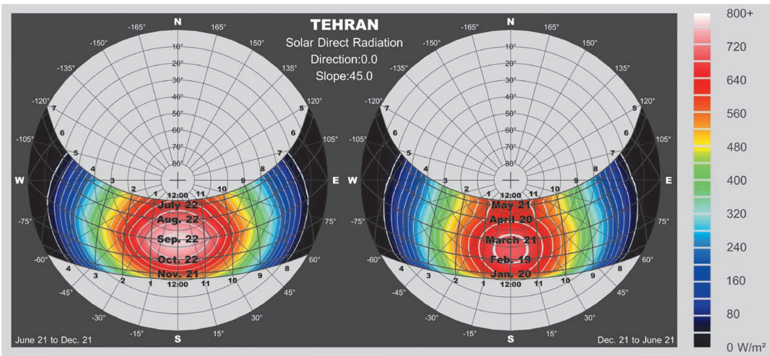


Fig. 92

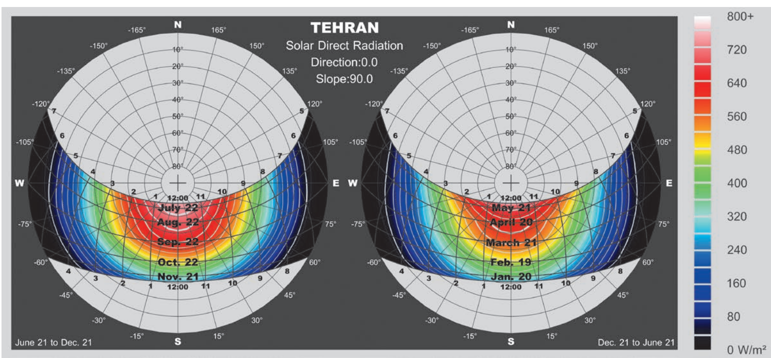


Fig. 93

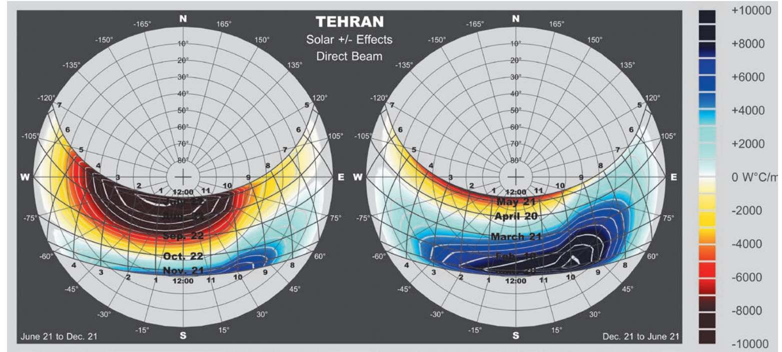


Fig. 94

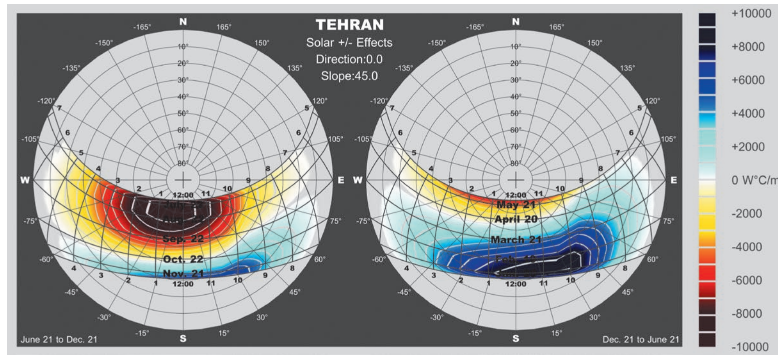


Fig. 95

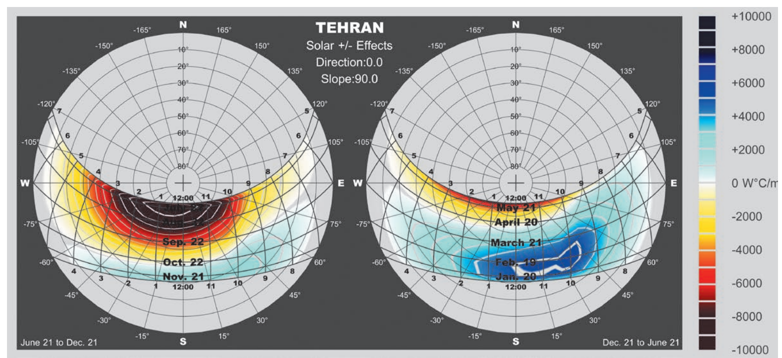


Fig. 96

Fig. 91–96: The amount of direct radiation (left) and its positive/negative effects (right) on different slopes, above: direct beam, middle: direct radiation on 45° slope to the south, below: direct horizontal radiation, SOLARCHVISION calculations based on long-term monthly data, IRIMO

Figures 91–93 illustrate the changes over time and the amount of maximum direct solar beam radiation as well as the different amounts received on a south-facing surface with a 45° inclination and a horizontal surface in Tehran. For a south-facing 45°-sloped surface, the maximum direct solar radiation occurs on 22 September at noon (Figure 92). In the case of a horizontal surface, the highest value is on 21 June (Figure 93).

Similarly, Figures 94–96 show the changes over time and the most extreme positive and negative effects of direct solar beam radiation as well as the different amounts received on a south-facing surface with a 45° inclination and a horizontal surface. For a horizontal surface, the maximum negative effect of direct solar radiation occurs on 22 July at 1 p.m. whereas the maximum positive value occurs on 19 February around 11 a.m.

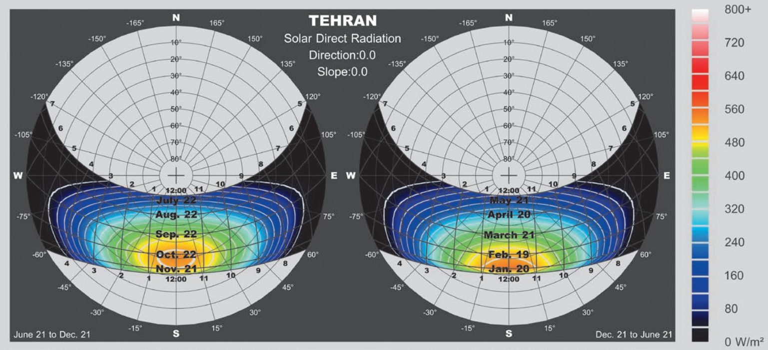


Fig. 97

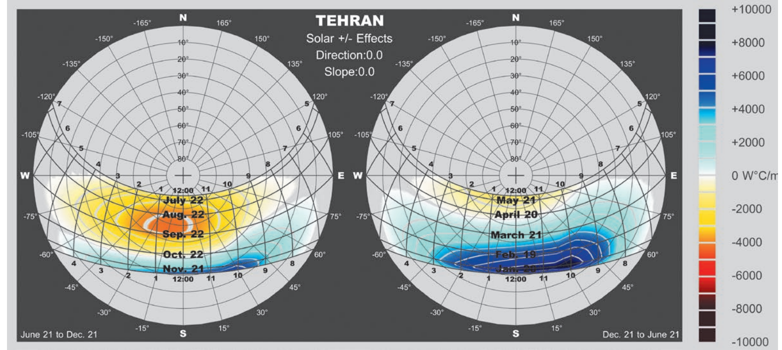


Fig. 100

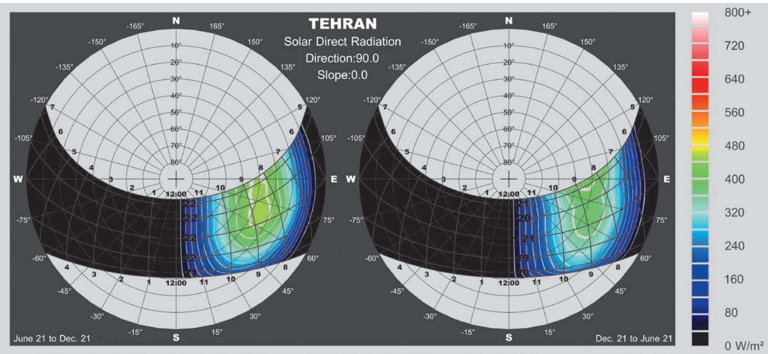


Fig. 98

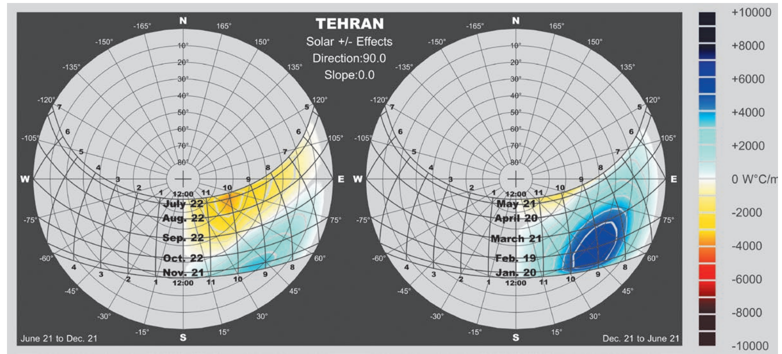


Fig. 101

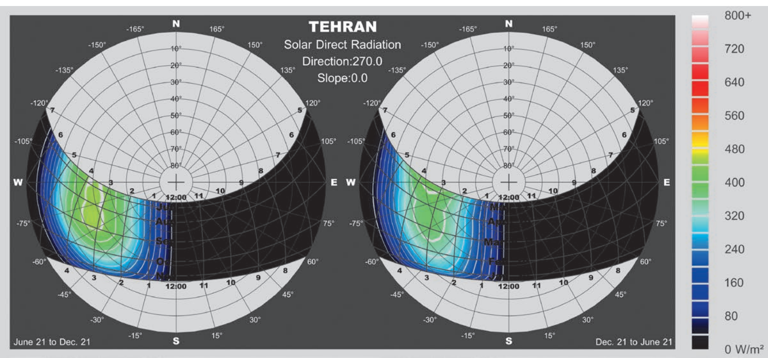


Fig. 99

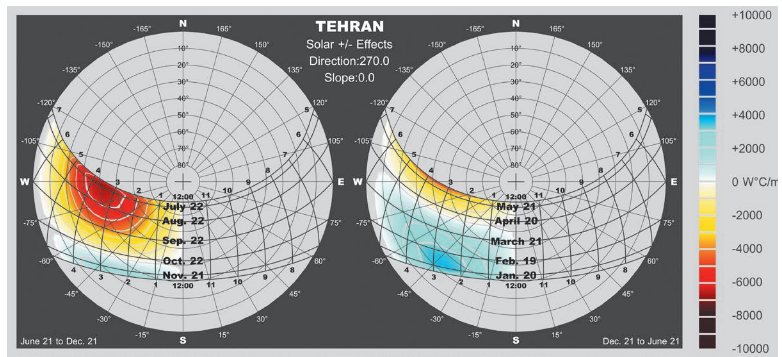


Fig. 102

Fig. 97–102: The amount of direct radiation (left) and its positive/negative effects (right) on different directions, above: south, middle: east, below: west, SOLARCHVISION calculations based on long-term monthly data, IRIMO

Figures 97–99 illustrate the changes over time and the amount of maximum direct solar radiation received on different vertical surfaces facing south, east and west in Tehran. For the south orientation, maximum direct solar radiation occurs on 20 January at noon. The value is highest on 22 August at 8.30 a.m. for an east orientation and at 3.30 p.m. for the west side.

Figures 100–102 show the changes over time and the most extreme positive and negative effects of solar radiation received on different vertical surfaces facing south, east and west in Tehran. For the south side, the maximum negative effect of direct solar radiation occurs on 6 September at 12.30 a.m. whereas, for the west orientation, the maximum negative value occurs on 22 July at 3.30 p.m. For the east side, the positive effects are at their highest on 19 February at 9 a.m.

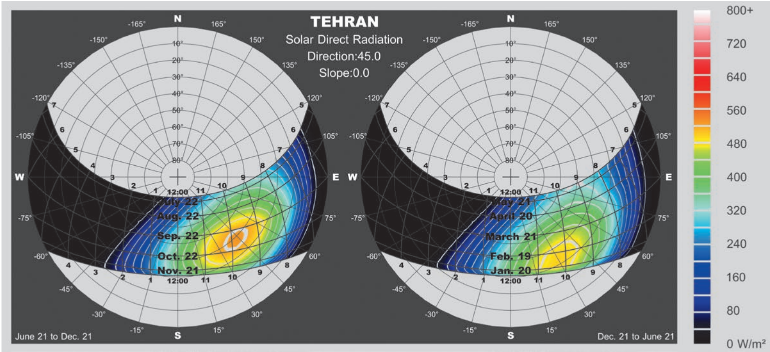


Fig. 103

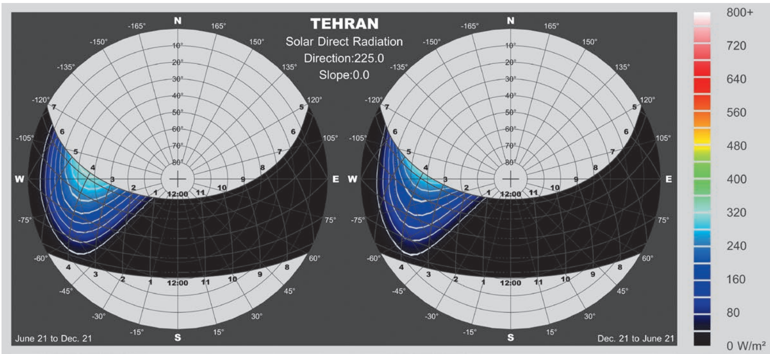


Fig. 104

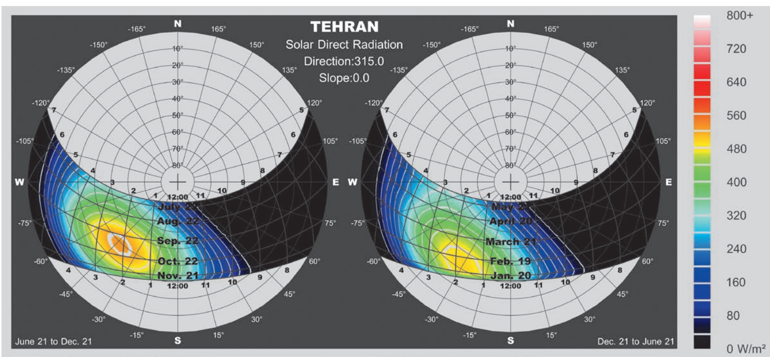


Fig. 105

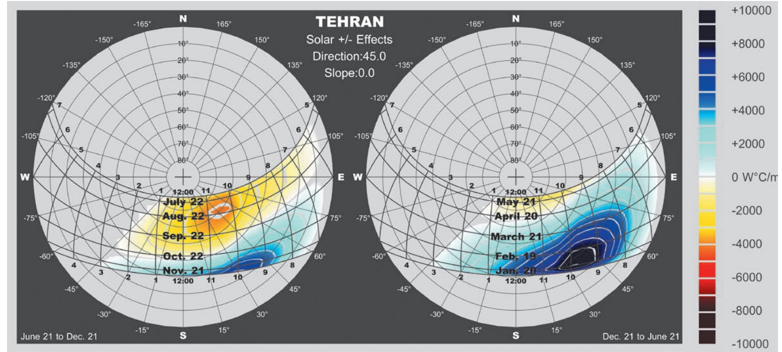


Fig. 106

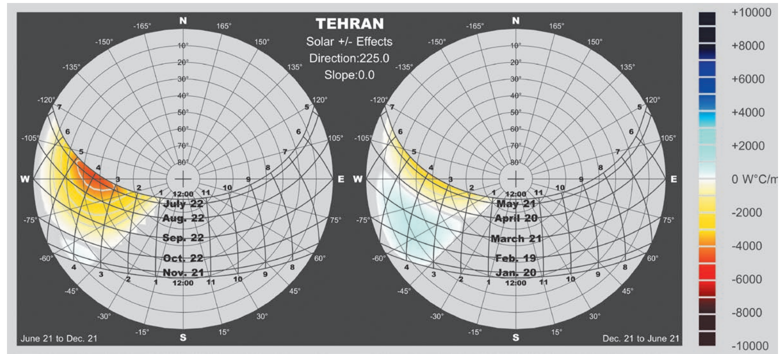


Fig. 107

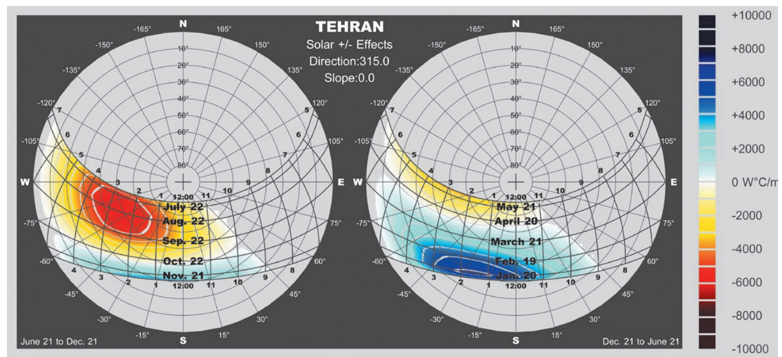


Fig. 108

Fig. 103–108: The amount of direct radiation (left) and its positive/negative effects (right) on different directions, above: S.E., middle: N.W., below: S.W., SOLARCHVISION calculations based on long-term monthly data, IRIMO

Figures 103–105 illustrate the changes over time and the amount of maximum direct solar radiation received on different vertical surfaces facing south-east, north-west and south-west in Tehran. For the south-east orientation, the maximum direct solar radiation occurs on 6 October at 10 a.m. The value is at its highest on 21 June at 4 p.m. for the north-west orientation and on 6 October at 2 p.m. for the south-west side.

Figures 106–108 show the changes over time and the most extreme positive and negative effects of solar radiation received on different vertical surfaces facing south-east, north-west and south-west. For the north-west side, the maximum negative effect of direct solar radiation occurs on 21 June at 4 p.m. whereas the maximum negative value for the south-west orientation occurs on 22 August at 2.30 p.m. The most positive effect for the south-west is on 20 January at 2.30 p.m. and for the south-east on 20 January at 10 a.m.

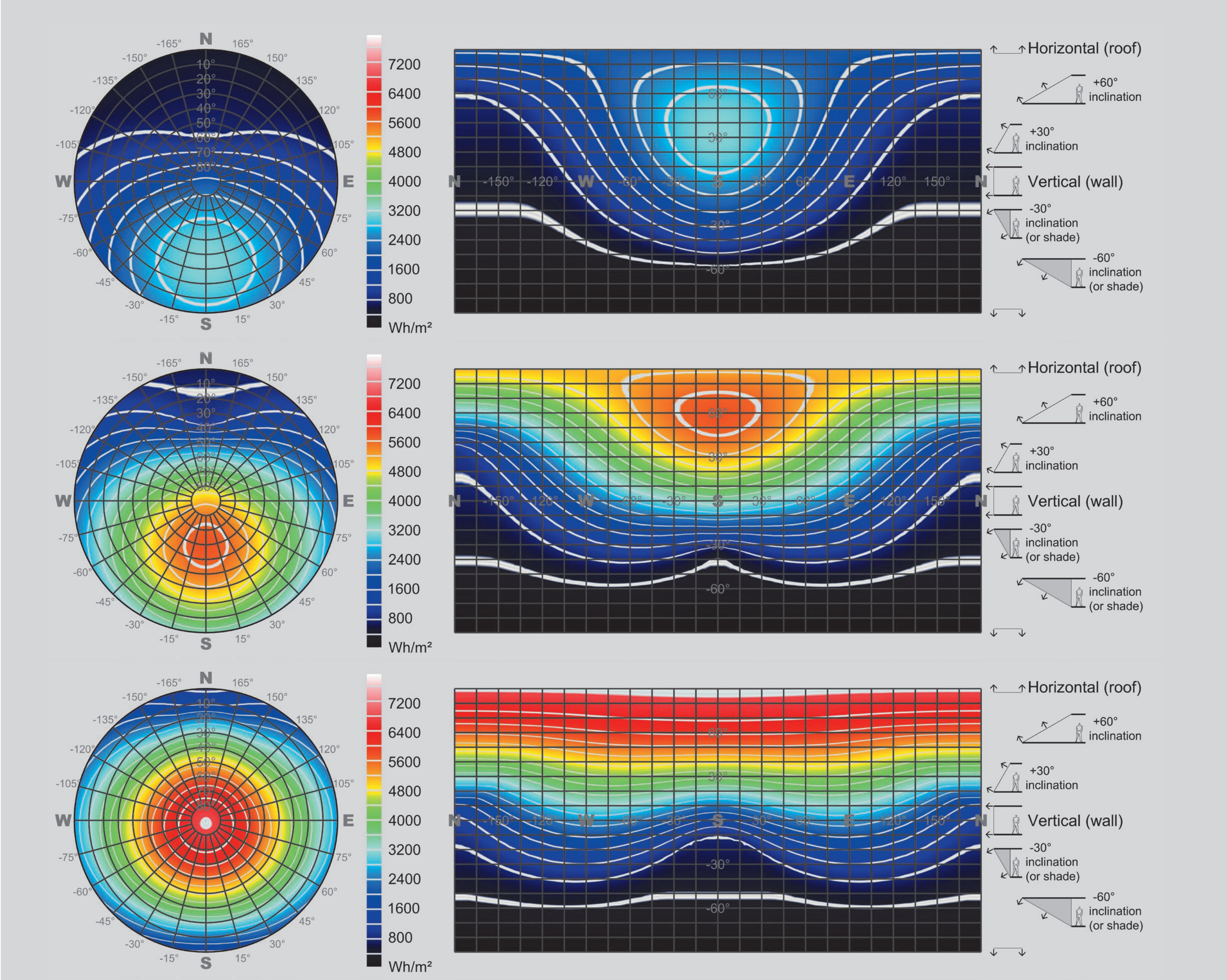


Fig. 109–111: Average total daily radiation on different surface orientations and inclinations in Tehran, above: 21 December, middle: 22 September, below: 21 June

Figures 109–111 present the total radiation received by each surface orientation and inclination in Tehran throughout different months of the year. The maximum value is achieved on 21 December for a south-facing surface with a 35° inclination, whereas it is on 22 September for a south-facing surface with a 60° inclination. The maximum daily amount of radiation occurs on a horizontal surface on 21 June; the south-facing surface receives a minimum amount of solar radiation in comparison with its other values in the other months of the year.

Figures 112 and 113 show the amount of total direct and diffuse solar radiation collected throughout a year; the maximum value is collected on a surface with a 75° inclination oriented true south. There is a large area plotted in green and yellow with high amounts of annual solar radiation; however, only a few orientations are generally considered to be suitable for the use of solar collectors and PVs. For example, the annual maximum total solar radiation is not always the most suitable, because an optimum distribution of the total annual amount in different months is a further key factor. The lower graphs show the optimization performed by the

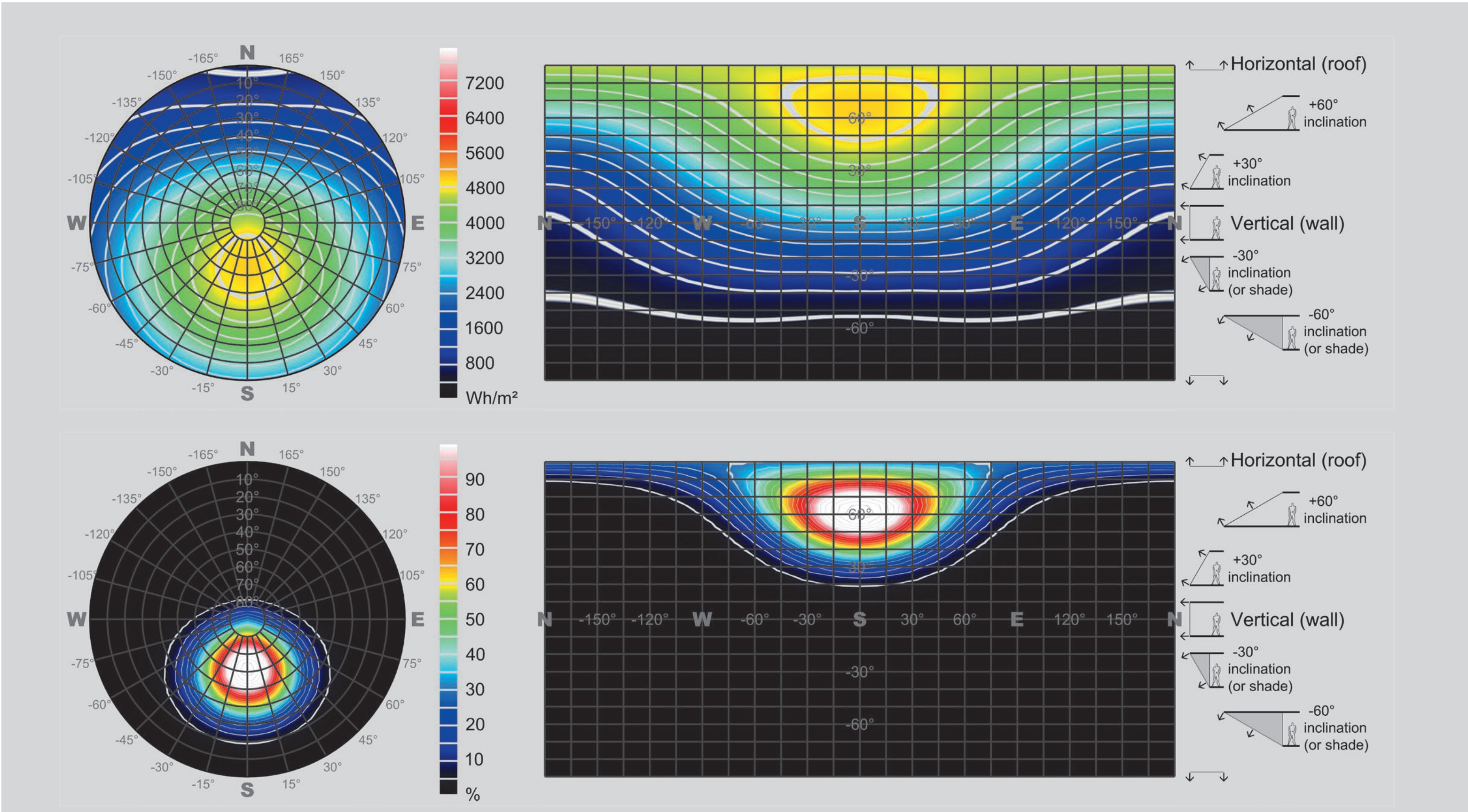


Fig. 112–113: Annual solar radiation on different surface orientations and inclinations in Tehran, above: total, below: active performance optimization

SOLARCHVISION computer program for rating different installation angles for solar thermal collectors and PVs. This study illustrates a range of orientations around 60° true south with a ±20° change and a ±15° inclination as the best orientations in Tehran for the installation of a single fixed PV or solar thermal collector on the roof; however, as described below, if more than one collector is available, different orientations and inclinations can be used to optimize the whole system.

In most cases, more than one collector is used to generate the required energy; thus, there are some reasons why the application of the ideal inclination, as a fixed parameter for all solar collectors, is not the best solution for locating multiple collectors, especially on flat roofs. Because of the shade each row creates, the second row has to be installed at a considerable distance to the neighboring ones (Figure 114, Diagram C).

On the other hand, multiple collectors can be put at different angles close to the most ideal orientation and inclination to produce even more energy by making use of reflections between the individual collectors (Figure 114, Diagram B).

Regarding the high price of solar collectors and PVs, the installation of a reflector in front of the panels can increase the performance and change the inclination (Figure 114, Diagram D). Advanced calculations can be performed by SOLARCHVISION to optimize these complex situations and increase the performance at the same time as reducing the costs.

The optimum distribution depends on the type of solar system (solar thermal or photovoltaic), the period of use and the purpose of the generated energy (e.g. lighting, heating, cooling); however, the best active orientation is the one which receives maximum total solar radiation during all months of the year. Taking Tehran as an example: despite the fact that the south direction, out of different vertical surfaces, is generally considered the direction which receives maximum solar radiation, it is possible, high altitude at noon as well as the fact that the sun radiates north instead of south in the mornings and evenings.

As a result, the annual amount of solar radiation is not the only factor which affects the active performance of each building direction during the year; thus, the potential of each direction should be studied carefully for each month.

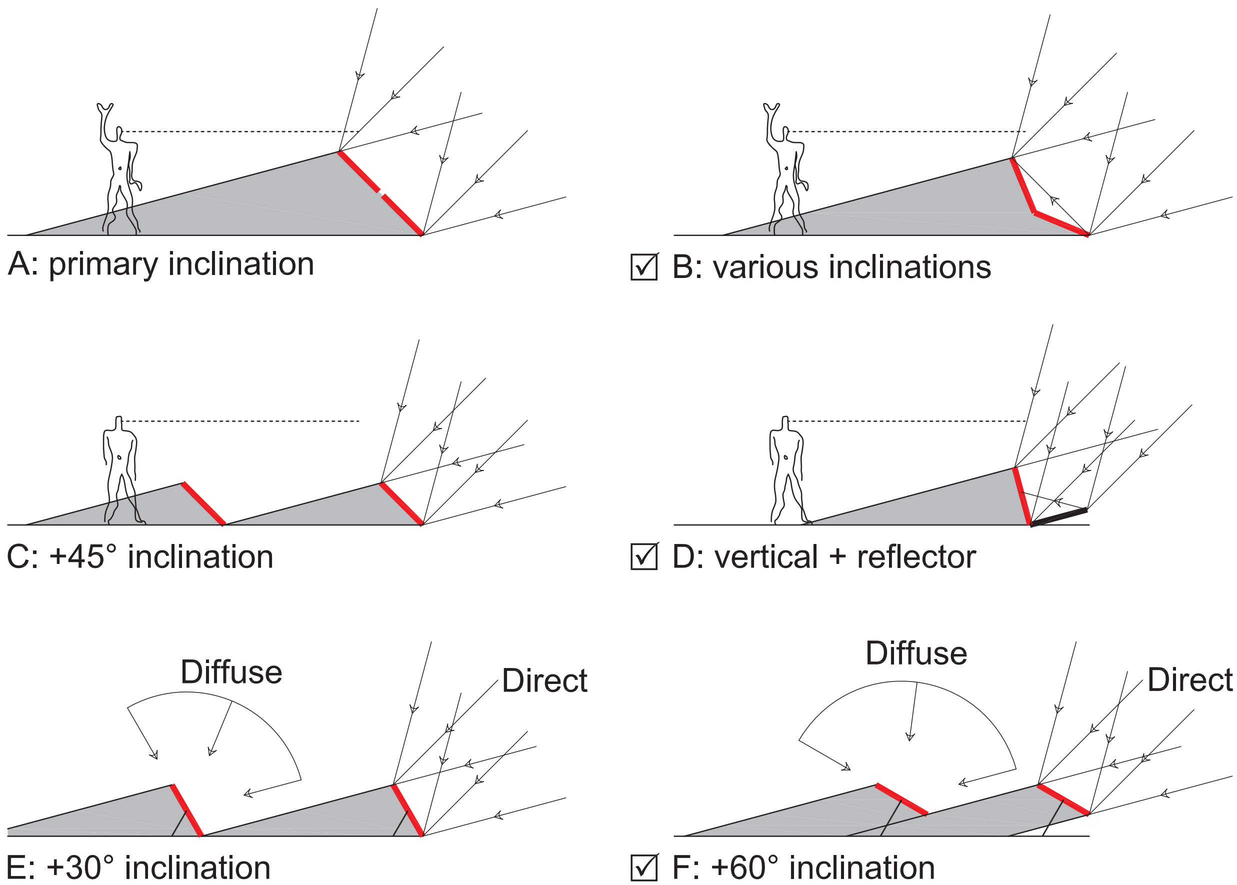
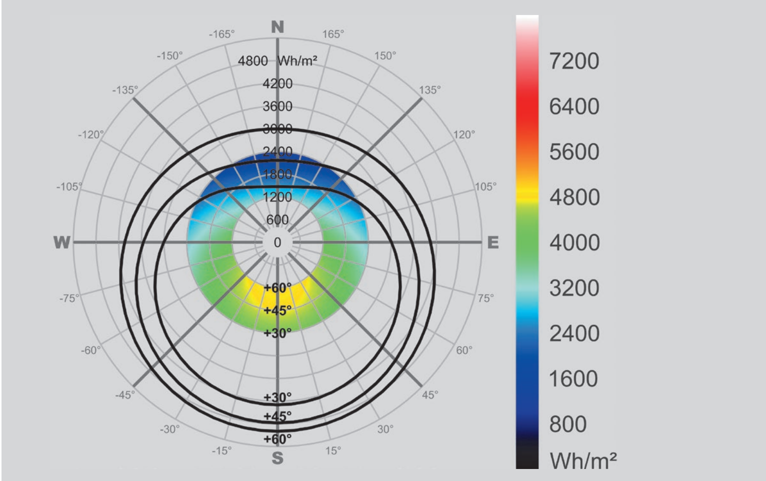


Fig. 114: Differences between layouts—the right layouts perform better

by optimizing a cubic building, to gain an equal amount of solar radiation from a south-east, south-west, north-west and north-east direction in comparison to that gained from a south, west, north and east direction. The average daily value gained from four vertical façades of a cubic building in a cardinal orientation is 1,800 Wh/m² throughout the year. This is simply because the amount of solar radiation received by the south façade decreases in summer (e.g. 1,500 Wh/m² in June) as a result of the sun's



Tehran Wh/m²/day	South	North	East or West	S.E. or S.W.	N.E. or N.W.
Annual	4,775	2,150	3,550	4,400	2,575
June	5,250	4,650	5,150	5,250	4,750
September	5,650	1,750	3,950	5,100	2,600
December	3,075	675	1,600	2,600	800

nations is not so significant in winter (21 December). On the other hand, the amounts of all directions ranging between S.E. and S.W. remain high. Hence, the use of a surface with a +60° inclination facing between S.E. and S.W. is generally suggested to produce the most energy in Tehran. In comparison, the use of a surface with a +30° inclination facing true south may slightly increase winter gains in a sunny situation; however, considering the more cloudy conditions during winter in Tehran, the use of a more horizontal surface (e.g. a surface with +60° inclination) should be considered the first choice as it captures more diffuse solar radiation from wider parts of the sky in winter. Furthermore, the performance during the other months of the year should also not be underestimated (Diagrams E and F on previous page).

If the architect wants to make use of the surfaces to generate solar energy, it is more suitable to consider the best active orientation and form, rather than the best passive orientation and form.

An example will help to clarify this concept: it is a fact that more solar energy can be generated from the sum of east and west surfaces than the sum of south and north (e.g. 12% for vertical faces in Tehran). In the case of sites that are located on a latitude equal or greater than 30°, it is difficult to convince a client to consider the generation of solar energy using a north direction. As a result, the sum of potentials for east and west

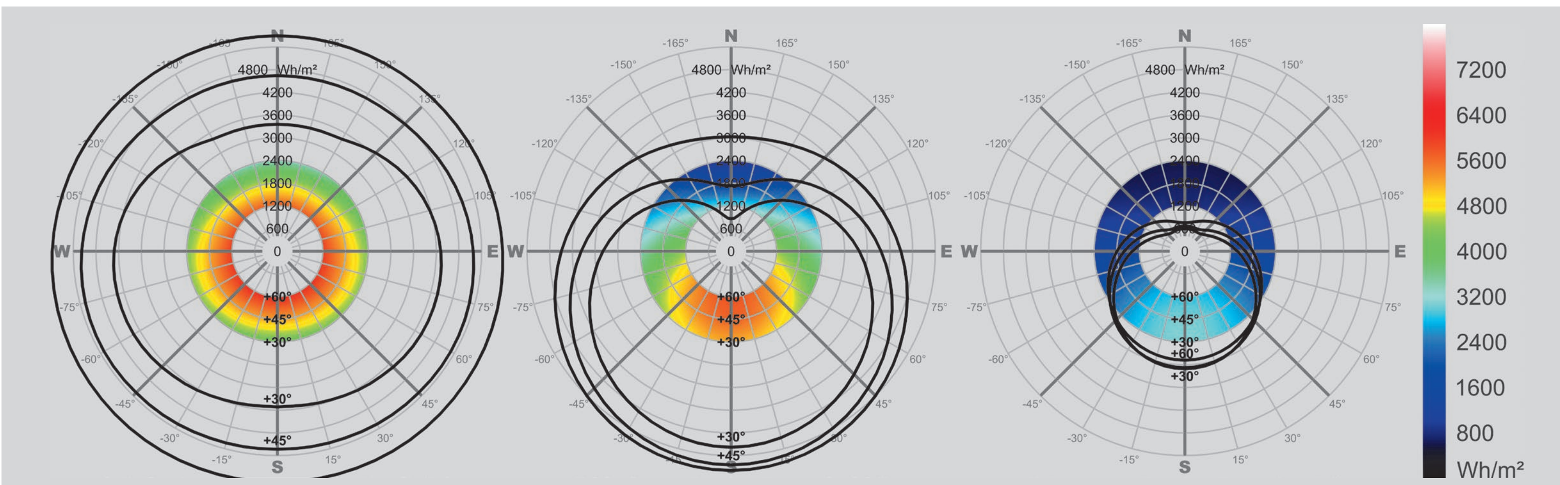


Fig. 115–116: Spherical and radial plots with the annual (above) and monthly averages (below) of daily solar radiation received on surfaces with inclinations between +30° to +60° facing different directions, left: June, middle: September, right: December
Tab. 1: Annual and monthly averages of daily solar radiation received on different oriented surfaces with an inclination of +45°

The monthly plots of average solar radiation received on surfaces with inclinations between +30° to +60° show different potentials in each direction as well as the variability during the year (Figure 116). In regard to this study, which was performed by SOLRACHVISION for the city of Tehran, more direct and diffuse solar radiation (about 40%) is collected by a south facing surface with a +60° inclination in summer (21 June) than on a surface with a +30° inclination. The difference between the two inclidirections reaches the value 3,800 Wh/m² (1,900 Wh/m² + 1,900 Wh/m²), which is quite significant in comparison to the potential of a south orientation with 2,700 Wh/m² (2,700 Wh/m²). This 40% increase is simply the result of having more façade area which can be used to produce solar energy using BIPVs for instance (Table 2).

Thus, by rotating the direction of a narrow building design from a traditional passive orientation, which faces south, to an active orientation, the building surfaces can produce more energy during the year. It is worth noting that this energy can help for cooling in summer as well as be used as a direct heat source in winter. On the other hand, shading devices are necessary to help protect the building envelope during certain times of the day and year. Shading devices could be also made of BIPVs to produce the electricity required for lighting with the available direct and diffuse solar radiation.

A major benefit concerning the concept of rotating building volumes away from a traditional passive true-south orientation (for instance from ±30° to ±90°) is the change in the time of generating energy, which is now newable energy sources is the variability and intermittence in their availability; significant mismatches between energy demand time and energy production time can occur." (F. Haghighat, 2013)

As explained later in this book, in comparison to a true south orientation of building mass, an east-west orientation as well as other deviated orientations (for instance ±45° deviations from true south) can also produce better outdoor conditions between the building volumes on a neighborhood scale as they are not subject to constant overshadowing in winter; furthermore, sufficient shade is provided by the urban fabric in summer (Figure 248).

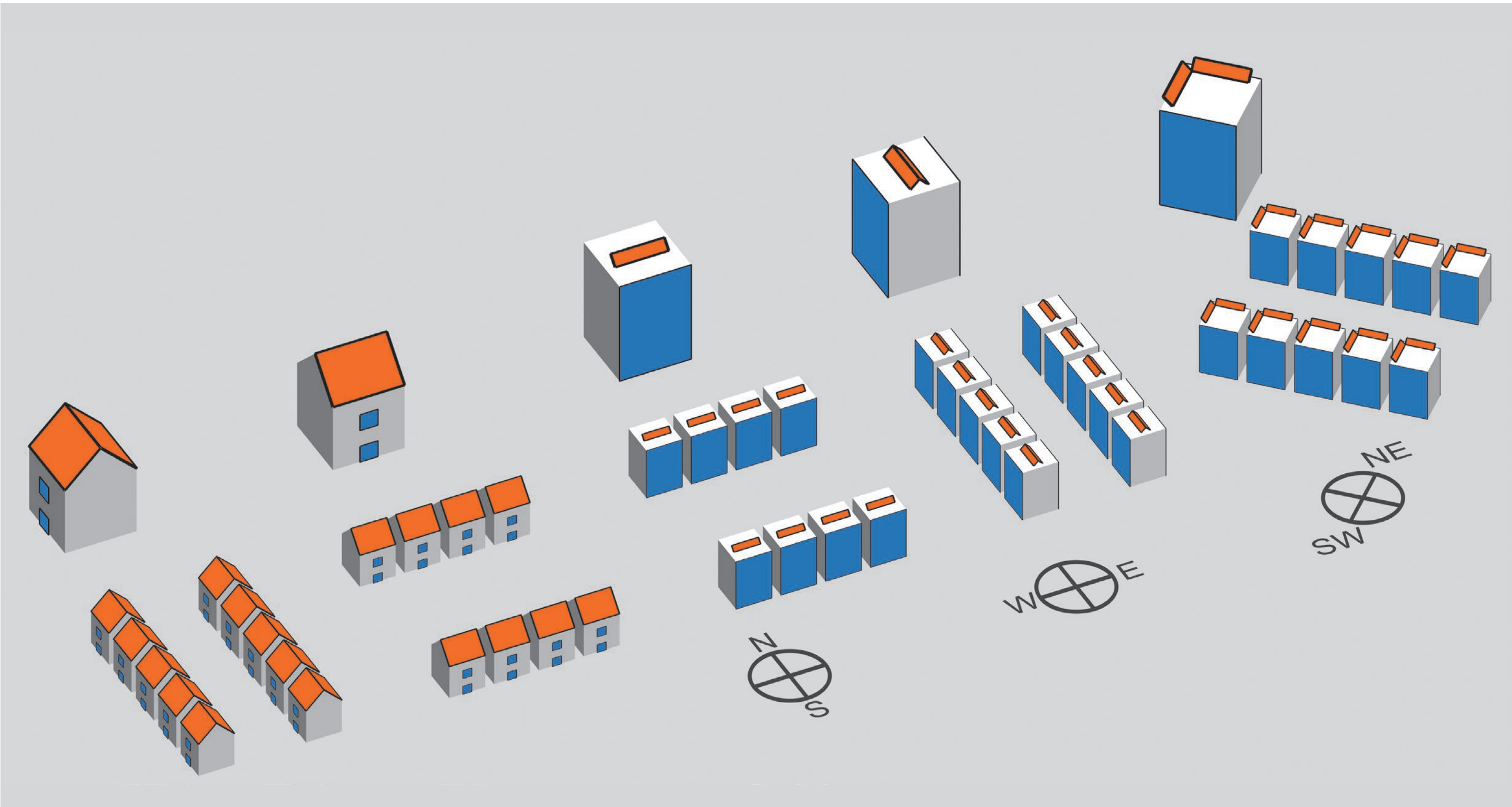
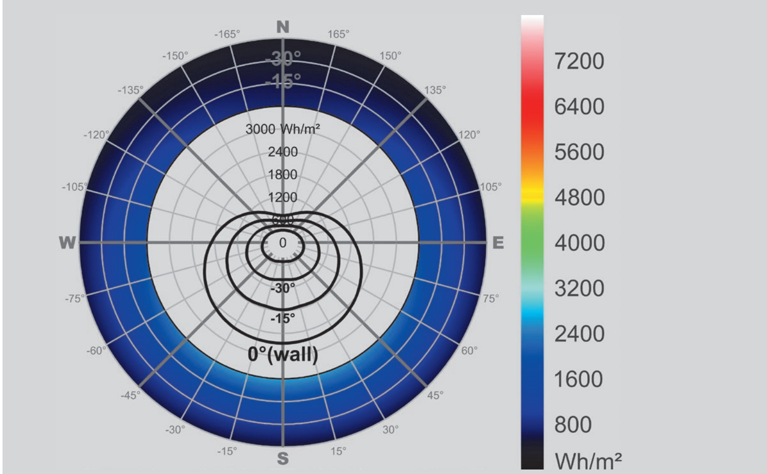


Fig. 117: Application of integrated systems as well as the possibility and need to perform fundamental changes during the planning phase, orange: solar thermal collector or photovoltaic), blue: glass or BPV

in line with the extreme needs of the building itself, as well as the possibility to smooth out the peaks within the cities' electricity grids (Figure 117–119).

"Presently, designers use guidelines developed for passive solar buildings to design net-zero energy buildings where the focus is on the design of a well-insulated and airtight building envelope. Then, the building is connected to an on-site source of energy. The main drawback of re-



Tehran Wh/m²/day	Single-sided South	North	East or West	S.E. or S.W.	N.E. or N.W.	Two-sided ½.(S.+N.)	½.(E.+W.)	½.(S.E.+N.W.)	½.(S.W.+N.E.)	Four-sided ¼.(S.+N.+E.+W.)	¼.(S.E.+N.W.+S.W.+N.E.)
Annual	2,700	700	1,900	2,500	1,100	1,700	1,900	1,800	1,800	1,800	1,800
June	1,500	1,100	2,600	2,250	1,950	1,300	2,600	2,100	2,100	1,950	2,100
September	3,400	650	2,150	3,000	1,050	2,025	2,150	2,025	2,025	2,087	2,025
December	2,650	450	950	2,000	450	1,650	950	1,225	1,225	1,300	1,225

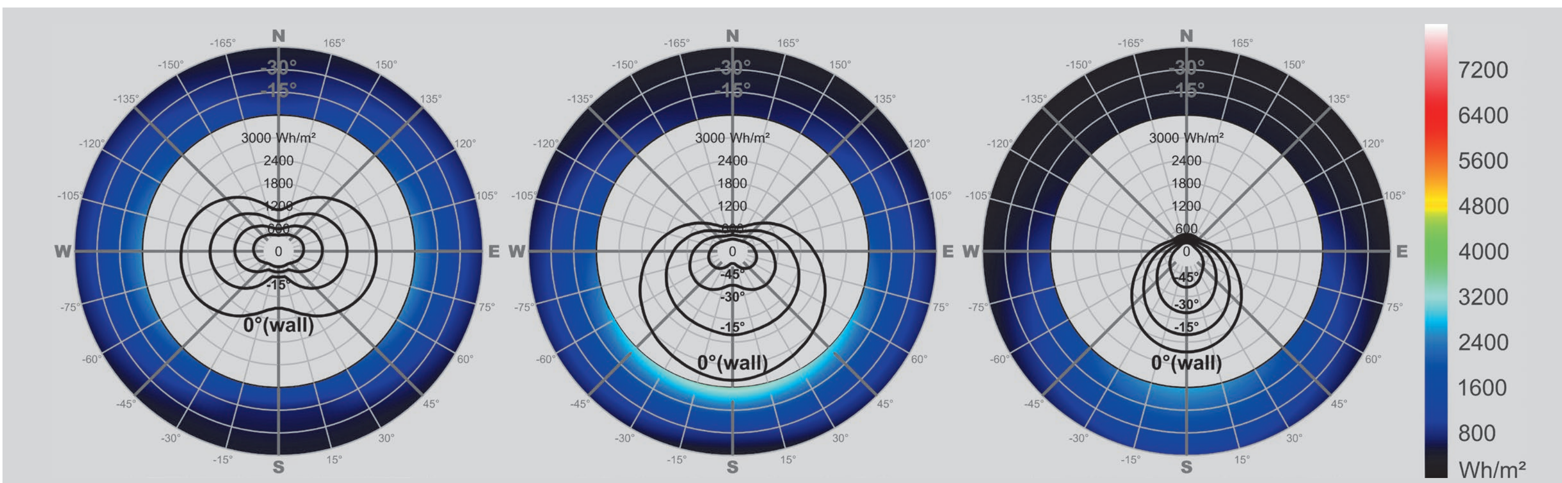


Fig. 118–119: Spherical and radial plots with the annual (above) and monthly averages (below) of daily solar radiation received on surfaces with inclinations between -45° to 0° (vertical) , left: June, middle: September, right: December
Tab. 2: Annual and monthly averages of daily solar radiation received on a vertical surface (wall/window/BIPV) facing different

The task of studying the effects of the sun on the different façades of building volumes over time is critical and should be performed for each site and each project with its particular situation.

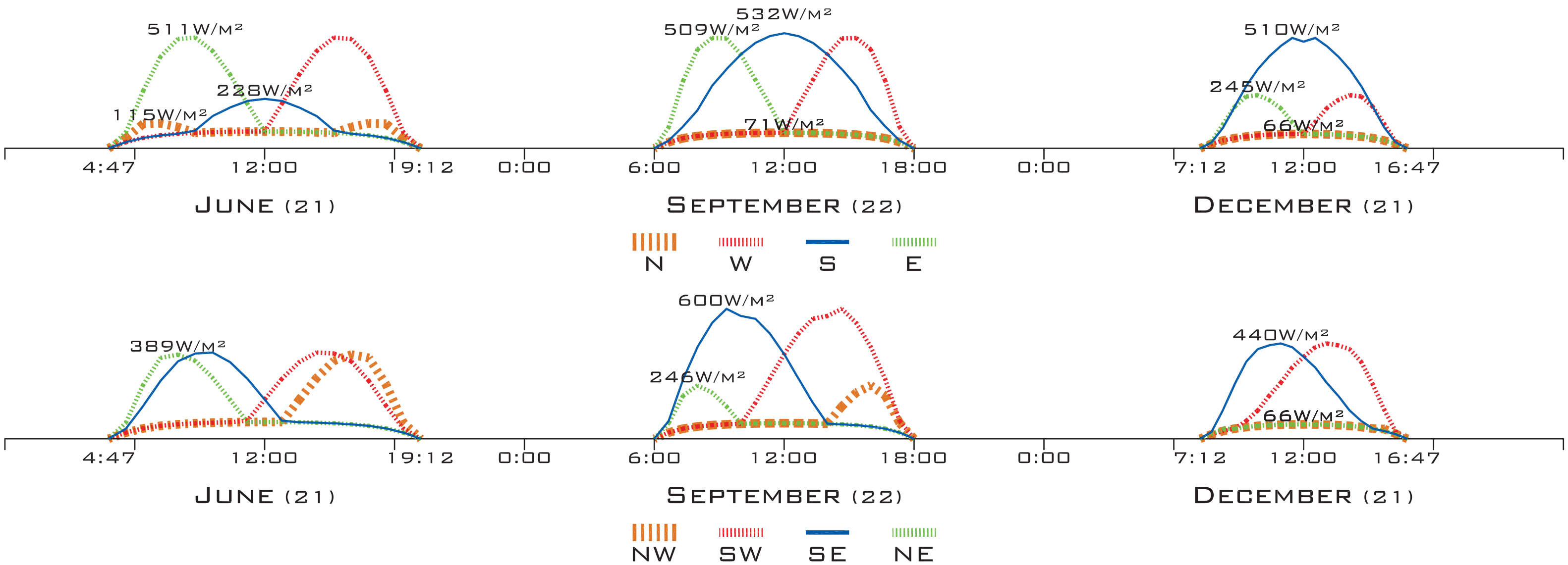
In regard to the development of new technologies in recent years as well as possibilities that might be available in future, there will be a fundamental change in the fashion of architecture thanks to the integration of solar thermal systems and photovoltaics. In this respect, the different building façades as well as the roof surfaces are considered as the farms to produce energy, which means that the potential of each direction should be examined carefully, including different parameters, such as the power generated in each direction, the area of integrated solar material/systems (e.g. BIPV or solar thermal system), the efficiency of the system (which is also a function of the angle of incidence), etc.

In contrast to aspects related to the production of energy using integrated systems and winter gains from windows during cold periods, solar radiation can directly affect the consumption of energy most significantly in the cooling period. Consequently, the study presented here is a key to performing adjustments to the design using both passive and active strategies. In this respect, the monthly values of average solar radiation received on surfaces with inclinations between -45° to 0° (vertical) have been presented here.

As one can simply figure out from the diagrams for Tehran, the amount of solar radiation on south-oriented surfaces is generally lower than that on east and west-oriented surfaces, and it is generally much higher in winter. This is the reason why a true south orientation is generally considered best and used by many to achieve comfortable conditions inside. On the other hand, plots incorporating surfaces with -15° and 0° inclinations show significant reductions in the energy received in summer (June), which means that a thin horizontal shading device can actually produce a lot of desirable shade in summer for a south-facing façade.

To conclude this discussion about active strategies here, it is always important that, in addition to the vast use of solar collectors and PVs, the right concept is selected which best suits the new solar technologies, climatic and energy related aspects.

Bearing in mind the simple physical fact that "hot air rises", solar energy can heat the air under a large translucent roof. Due to the chimney effect, the updraft wind in the central vertical tower drives turbines to generate electricity. (Jörg Schlaich and Rudolf Bergermannh Solar GmbH, *http://www.solar-updraft-tower.com/en#technical_concept/index*)



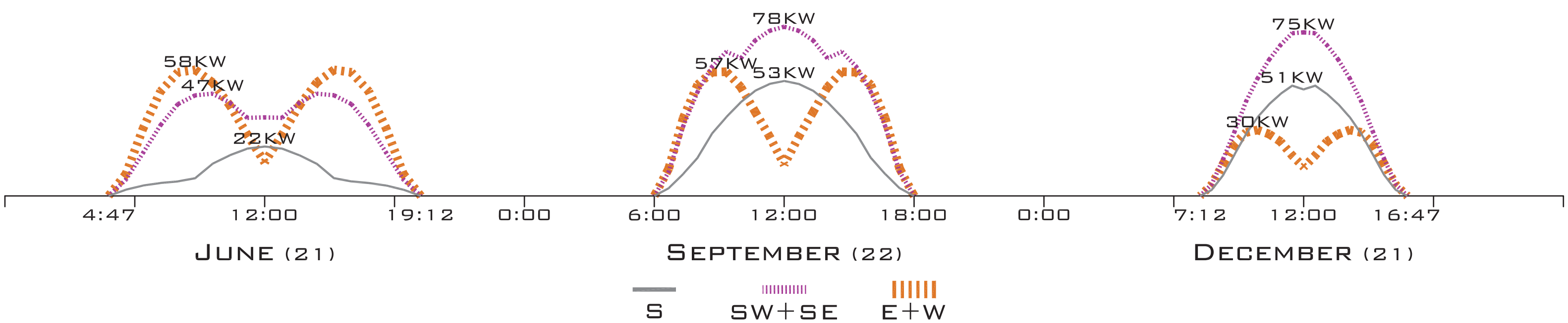


Fig. 120–121: Hourly plot of total (direct and diffuse) solar radiation on different vertical surfaces for different months in Tehran
Fig. 122: Hourly plot of total solar radiation on different sides of a 10x10x10m cubic building in Tehran to show the potentials of different orientations

In addition to this, it is always necessary to consider passive measures in connection with active solar approaches to generate energy. For example, if the target is to build a high-rise tower as an icon for a city you have two choices. The first one is to draw a strange looking, but ordinary high-rise tower and then have a large plant of solar photovoltaics at the bottom to convince everyone that it is somehow a green design; the second choice is to integrate passive and active concepts in a solar updraft tower.

Considering all existing ordinary buildings that we have, passive strategies are still economically and ecologically more practical and sustainable. In comparison to active strategies, these require less equipment which in turn leads to a lower consumption of resources for the production of the appliances as well as lower installation and operation costs.

In this regard and in order to return to the subject of the sun's positive and negative effects in each location, it has been possible to illustrate the differences between an east and west orientation. The amount of solar radiation on east and west façades is almost the same. Generally, the solar radiation of a west orientation has more negative effects because of the higher temperatures in the afternoons in comparison to those in the mornings (compare Figures 98, 99, 101 and 102).

The Figures 123–124 present the annual positive and negative effects resulting from the direct and diffuse solar radiation on different surface orientations and inclinations in Tehran. According to the upper blue graphs, the positive effect of the sun in Tehran has remarkable values for

This is due to the fact that the roof is more exposed to the sun in hot periods; whereas the amount of direct solar radiation reaching a vertical south-facing surface is reduced on summer days due to the azimuth and altitude of the sun.

The negative effect of the sun is high in Tehran for different vertical surfaces facing between west and south and positive inclinations. The most negative effect of the sun during the year is on a south-west-facing surface with an inclination of 75° (almost horizontal). On the other hand, as Figures 123 and 124 show, these negative effects can be reduced by us-

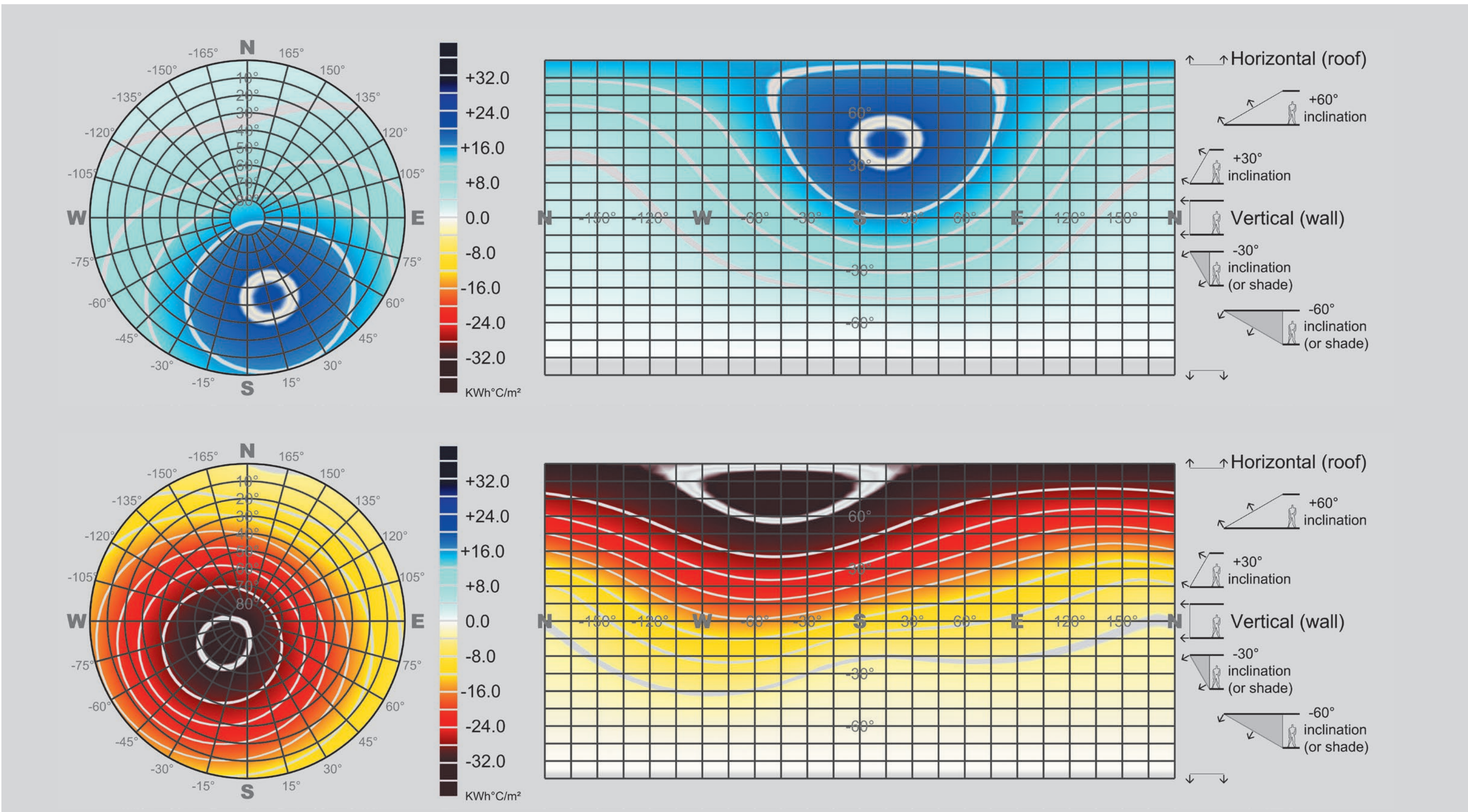
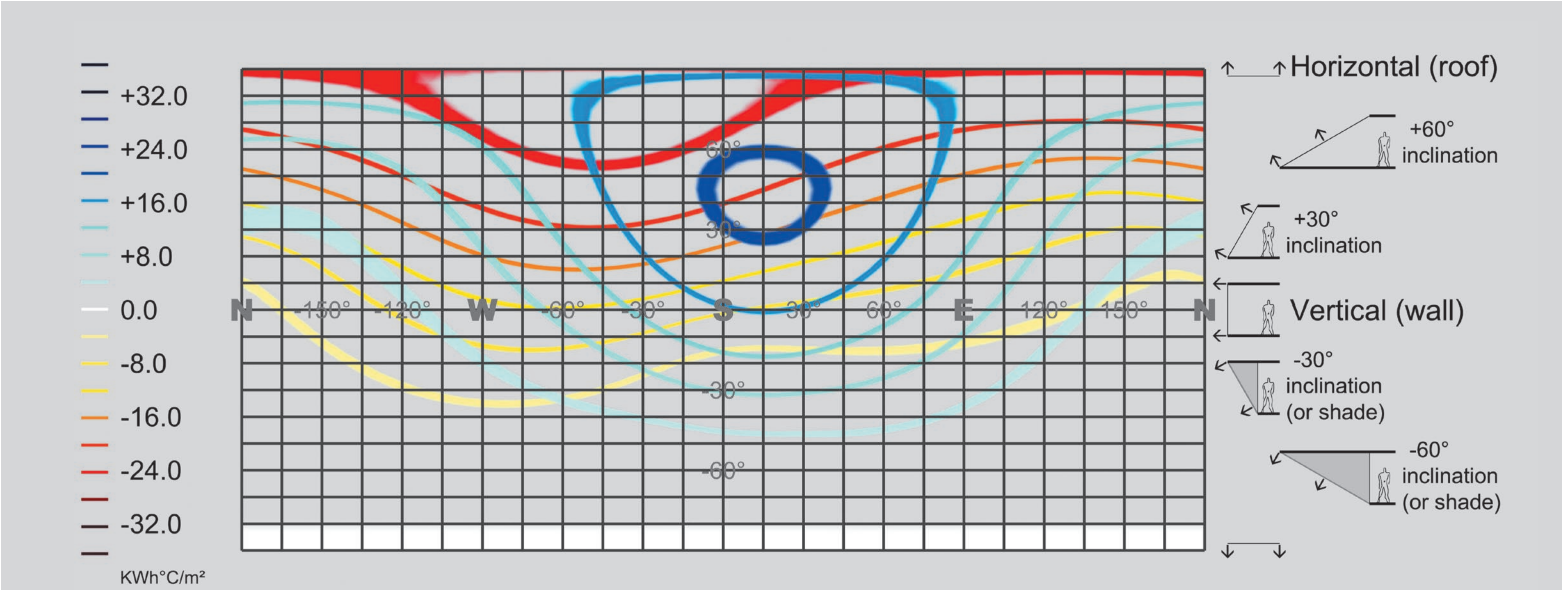


Fig. 123–124: Annual positive (above) and negative effect (below) of the total radiation on different surface orientations and inclinations in Tehran

different vertical surfaces ranging from west to north-east with negative as well as positive inclinations. The annual positive effect of the sun is highest on a south-facing surface with a 10° rotation to the east and an inclination of 45°. In Tehran, the annual positive effect of the sun is equal for a south-facing vertical surface and a horizontal surface (roof); while the negative effect of the sun on a south-facing surface is much lower than that on a horizontal surface (roof).

ing either a negative inclination in the façade or a horizontal shading device in front of the window.

In comparison to the analysis of directions and inclinations for an active strategy, the analysis for a passive strategy is more complex. As each face receives both positive and negative effects during the period of analysis (e.g. the annual cycle), efficient functions are required to rate different surfaces in regard to a variety of possible high and low positive and



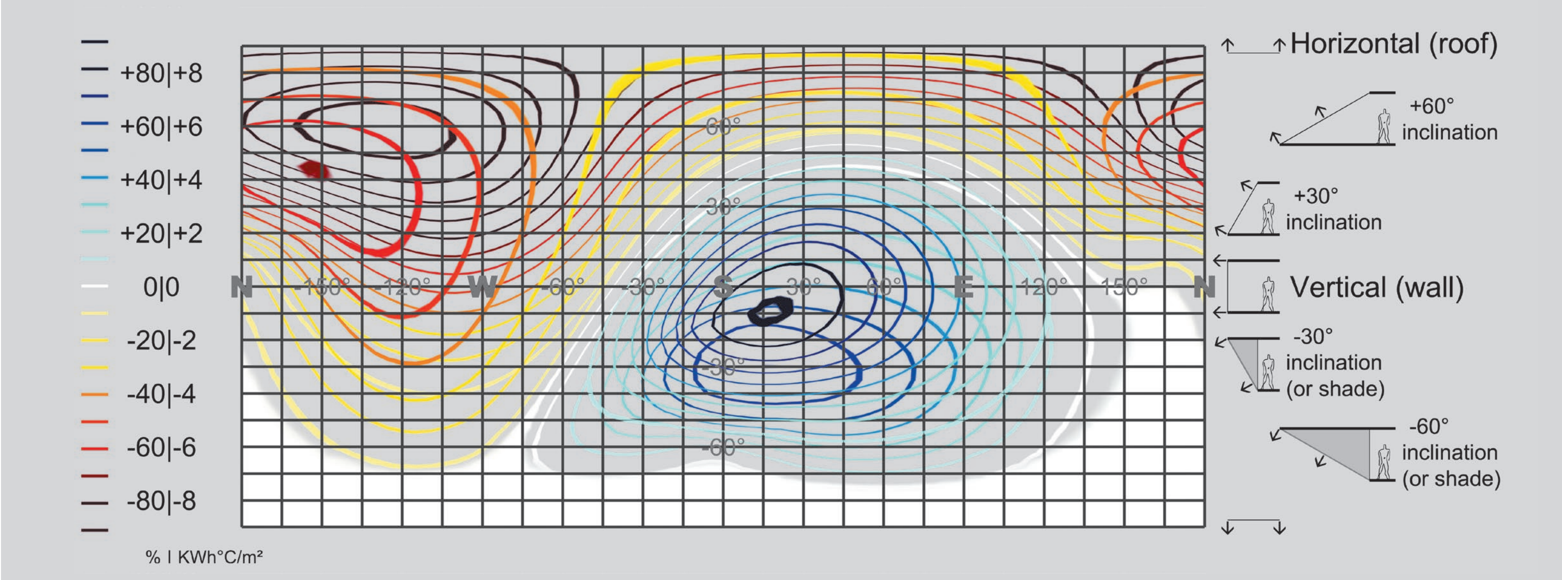
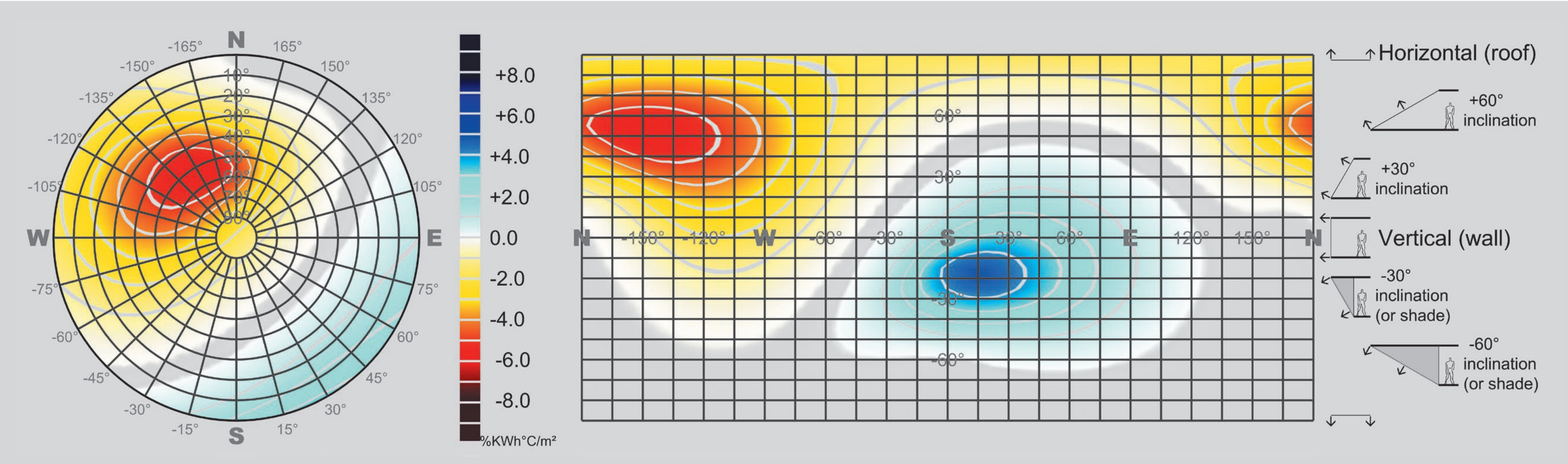


Fig. 125: Overlay of contours from the annual positive and negative effects of solar radiation on different surface orientations and inclinations in Tehran
Fig. 126: Overlay of contours from two analytical layers of ratios and the total positive and negative effects of solar radiation on different surface orientations and inclinations in Tehran

negative gains. The SOLARCHVISION computer program, which is based on a mathematical method and was developed in the dissertation titled "From the Sun to the Architect, 2007", uses a multiplication between the two analytical layers of sum and ratio of positive and negative gains, as was then published in greater detail in the paper "A New Approach for Solar Analysis of Buildings" in Worldcomp '08.

The tables in Figures 125 and 126 illustrate the annual negative and positive gains for the city of Tehran as well as the result of two primary analytical layers based on the values at each point of the table in regard to its direction and inclination. Notably, the multiplication between the two primary analytical layers, which leads to final rates in the passive analysis, is similar to what actually occurs in the brain with two images seen by two eyes, which is called "Stereopsis".



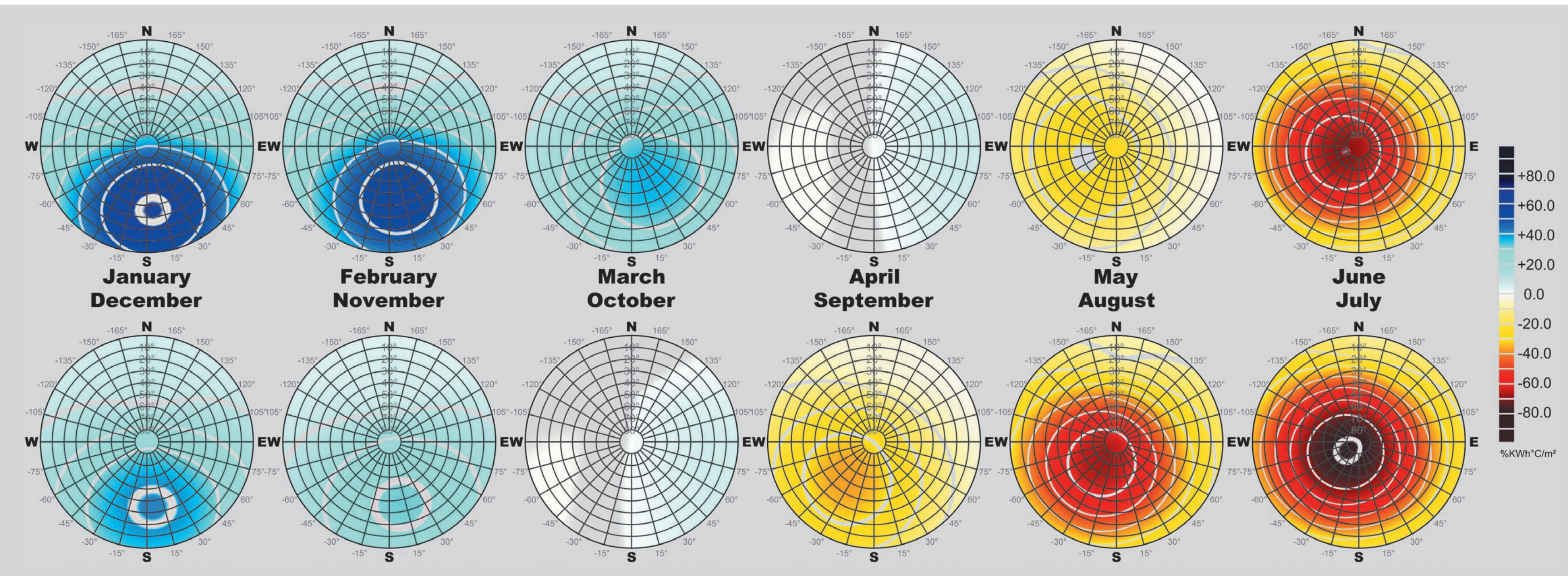


Fig. 127: Analysis of annual solar positive and negative effects of direct and diffuse radiation on different surface orientations and inclinations in Tehran
Fig. 128: Monthly analysis of positive and negative effects of direct and diffuse radiation on different surface orientations and inclinations in Tehran

The annual analysis, which is presented in Figure 127, clearly illustrates that the best positive orientation of a building façade is between south and east and between an inclination of -30° and 0° (dark blue area). The graph also shows that the most negative orientation in Tehran, using a passive strategy, is around north-west with an inclination between +20° and +75°. The solar effects of these orientations are particularly negative in summer. On the other hand, the solar effects of the orientations in the red area are not particularly positive in winter either. Consequently the red, orange and yellow areas concern façades of buildings which are better not opened extensively without shading devices. On the other hand, a decision must be taken for façades located in the middle areas highlighted in white. Regarding the monthly and hourly situation, the performance of these orientations can be improved by using static or interactive shading devices.

Fig. 129: "It never rains but it pours", Khur Saltlake (Hossein Farahani)

Limitation of energy resources, pollution, heat island effect, climate change and global warming are some of the current problems and future challenges that the human race has to deal with. In regard to the major impact and the critical role of human interference in the environment, viewpoints should be changed and new horizons should be discovered within the foreseeable future to at least reduce the speed of these ever increasing problems. Even if it is obvious, it is necessary to mention here that the role of people who live inside buildings, the architects, clients and builders who design and construct the buildings and the planners and municipalities and so on who make decisions on major development plans bear responsibility together. Sustainability is not an architectural fashion; meanwhile, a beautiful design is the one which tries to adapt to the environment, whether natural or built, and integrate the contextual factors at the same time. A fundamental step to achieve such integration in

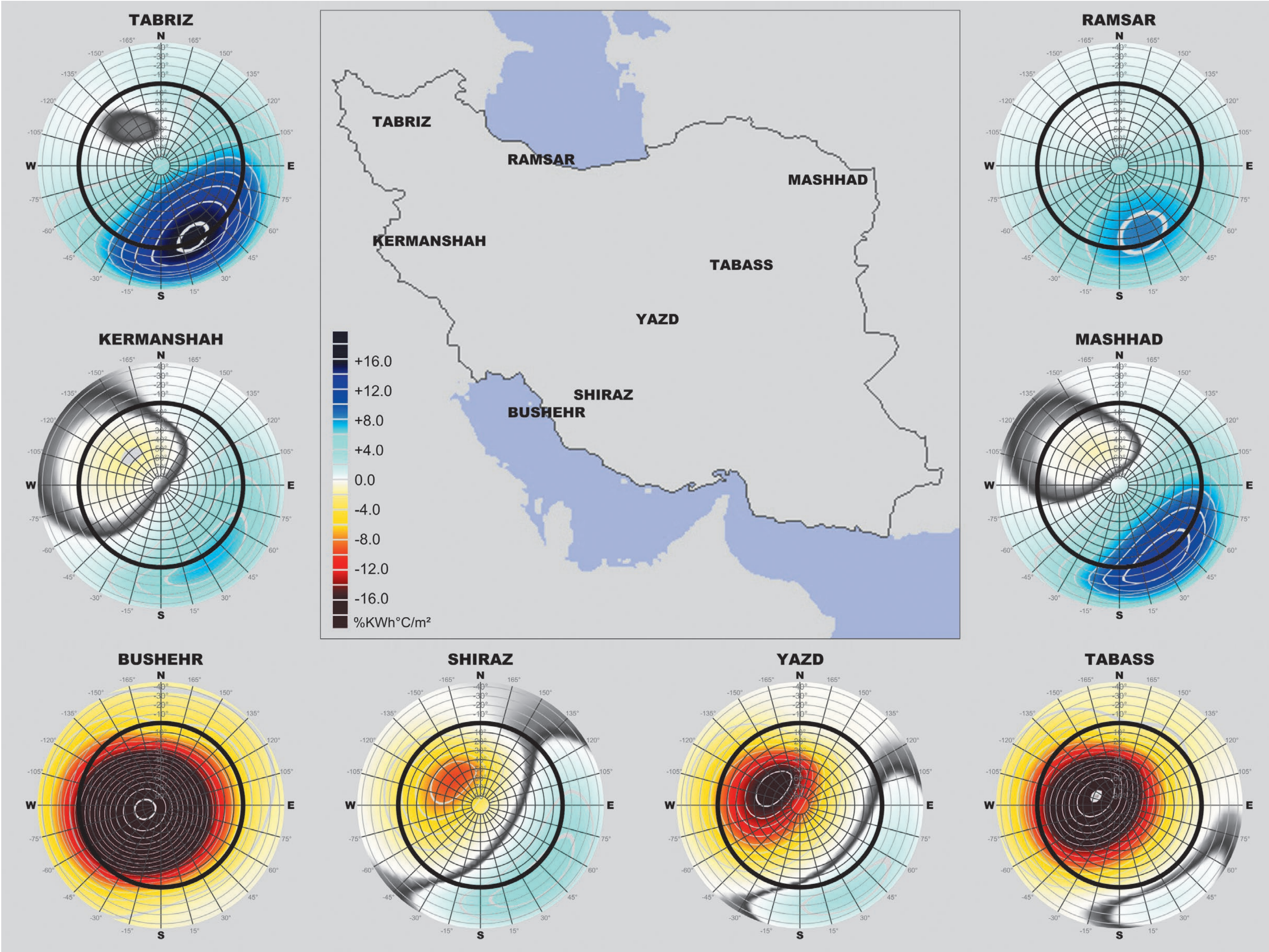


Fig. 130: Passive analysis of different surface orientations and inclinations (from -45° to +90°) for different cities in Iran

architecture and combat global problems is to localize solutions in regard to the differences in climate, available resources and local needs.

According to the example of Iran, with its notably complex and diverse climates, some facts and factors are illustrated in this section which are somehow related to the subjects described in this book. Some of these complexities are highlighted by looking back to the Figures 85 and 86. In consideration of the variable positive and negative effects of solar radiation during the year, architectural adjustments should be studied carefully to achieve climatic responsive spaces which provide comfort inside and outside buildings during both the cooling and heating period.

On the other hand, the graphs of Figure 130 illustrate the variety of conditions in Iran which require the application of different strategies in the architectural design and urban planning. The grey line separates the surfaces which require a shading device (red and yellow) from the other surfaces which are positive in terms of their solar-climatic performance throughout the year. These graphs are considered basic information for architects for the orientation of building mass and space. They are useful for establishing, in the design concept, the right relation to the sun and climate properties of the site and, in particular, the daily and monthly patterns of temperature change throughout the year.

As vast energy resources were not available in the past for cooling (and heating) the building, more attention has been paid to the passive functions of buildings in traditional local instances. However, as discussed, it is still critical to pay attention to the passive performance of buildings for a number of reasons. By applying these considerations in the architectural design, the energy demand of the building decreases significantly. That is because the application of these approaches leads to a maximization of solar heat gains in the heating period and a minimization of solar heat gains in the cooling period, which has the effect of decreasing both the heating and cooling energy demand. This in turn reduces the size and complexity of HVAC systems that are otherwise required to heat and cool the building. Furthermore, by increasing the solar-climatic performance of the building envelope, as a result of the architectural design, the indoor climate is more comfortable and healthier.

Fig. 131–132: Two different views of local architecture in humid and dry climates in Iran; above: Sobatan village, Talesh, below: Pirnia house, Nain (Hossein Farahani)

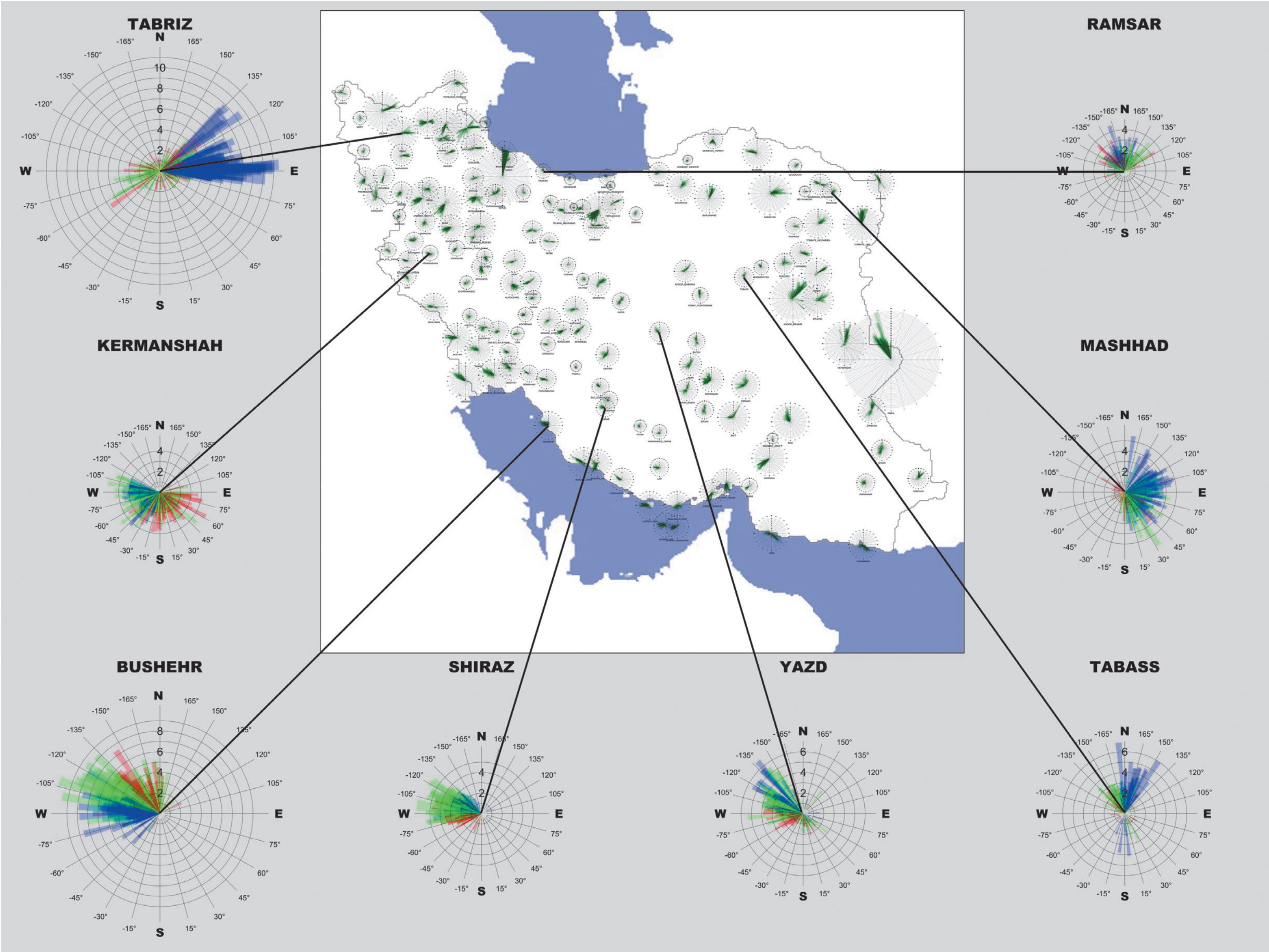


Fig. 133: Direction and speed (in knots) of the prevailing winds in different seasons for 8 cities of Iran, red: summer, blue: winter, green: spring & autumn

The diagrams presented in Figure 133 show the findings concerning the patterns of the prevailing winds for different cities in Iran. Alongside the basic graphs illustrating the passive analysis of different surface orientations and inclinations, the study concerning the direction and speed of the prevailing winds in each location can also help urban planners and architects to consider the climatic properties of each location at a very early stage of the design.

The observance of these parameters is fundamental, and non-compliance will be detrimental to the development. Iran's most populated city, Tehran, is positioned in an area with the country's lowest wind levels. The polluting industries are located on the west side of the city, which is the direction of the prevailing winds. Due to the high energy consumption of buildings and vehicles within the city, air conditions are very unhealthy for several days during the year. As a result, according to

Fig. 134: Application of wind energy in traditional Persian architecture, a water reservoir (Ab-anbar), Meybod (Hossein Farahani)

the Air Quality Index (AQI), the city had 215 and 3 "unhealthy" and "very unhealthy" days in 2011 respectively (Nasrollahi et al., 2013). Asaluyeh, which is a coastline in the Persian Gulf near the city of Bushehr, suffers in a similar way. The location of the natural gas refining facilities and petro-chemical factories are in the path of the prevailing winds, which regularly leads to bad air conditions in the residential area.

In contrast to these poor decisions, which were made in the 20th century in Middle East regions, there are some unique examples of climatic-responsive architecture and urban fabric within ancient cities and villages in the diverse climate of Iran (e.g. Bushehr, Yazd and Esfahan) as is the case in other countries, too.

By comparing the maps of the hourly solar +/- effects for cities in Iran (Figures 85 and 86) with similar maps of other locations around the world (Figures 78–84), two extremes concerning the situation of the sun can be

Fig. 135: Application of wind energy in traditional Persian architecture, Nashtifan windmills (Hossein Farahani)

identified in Iran: a significant amount of solar radiation and a remarkable change in daily and monthly temperature. Basically, this bold situation in different locations in Iran is the result of a number of factors namely low relative humidity, diversity of elevations, and the distance to the sea, mountains and deserts.

There are a variety of climatic conditions in different parts of Iran each of which requires its own unique architectural solution in particular concerning the relation to the sun. Consequently the word Mehraz, which means architect in Persian, is based on two words: “Mehr which means sun, balance, etc.” and “Raz meaning mystery”. Thus, ancient Persian architects were regarded as the ones who knew about the equilibrium as well as mysteries of the sun. The studies of traditional buildings in different cities of Iran show a direct relationship between the depth in each cardinal direction and the passive solar-climatic performance of the in-

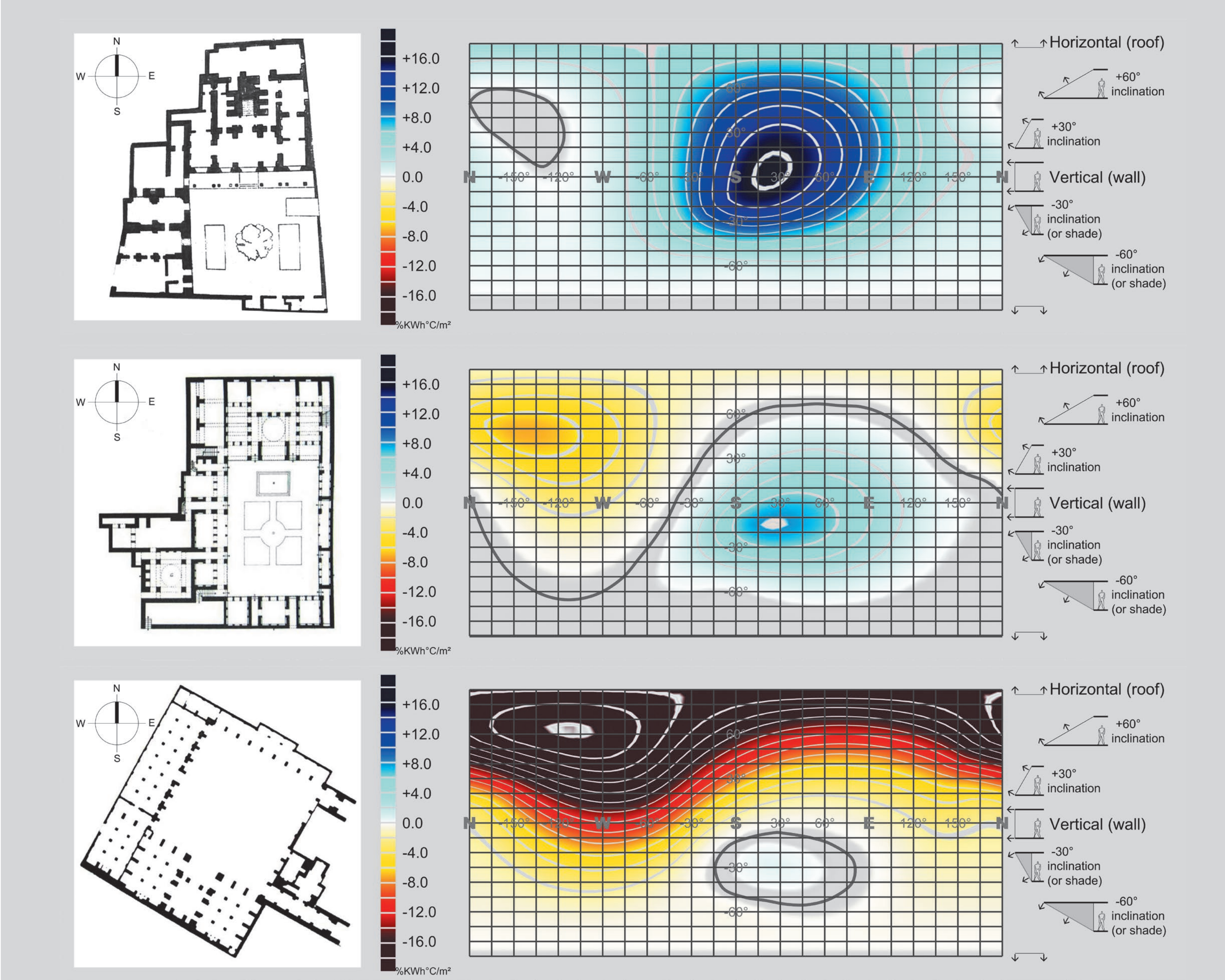


Fig. 136–138: Passive performance for each orientation and depth of a traditional building, upper left: Tabriz (Shirzadeh et al. 1987), lower left: Esfahan (Haji-Ghassemi, 1998), right: Tabass (Plan for Reconstruction of Tabass, 1980)

dividual orientations. Past and future studies in this matter can demonstrate the integration of architectural elements in traditional Persian architecture on different scales, ranging from the urban environment to a single building façade.

III
Solar-Climatic Spatial Analysis in Design

In regard of the building skin's fundamental role in finding the most appropriate relation between outside and inside, the layer should be designed in a way that it not only benefits from external positive conditions and resources but is also protected from unfavorable aspects inside natural and built environments. Considering the effective role of architectural design and urban planning in terms of providing health, comfort and safety for mankind, the development of new tools and methods for the optimization of a building's performance is helpful to reduce energy consumption, pollution and greenhouse gas emissions as well as other negative effects produced by structures in natural and built environments. In connection with local and global challenges, a solar-climatic analysis of the architectural concept (using architectural elements, proportions, orientation, etc.) and its application in the early design stages can directly and significantly improve the interior conditions of buildings and decrease their energy demands. Nevertheless, the effects of overshadowing

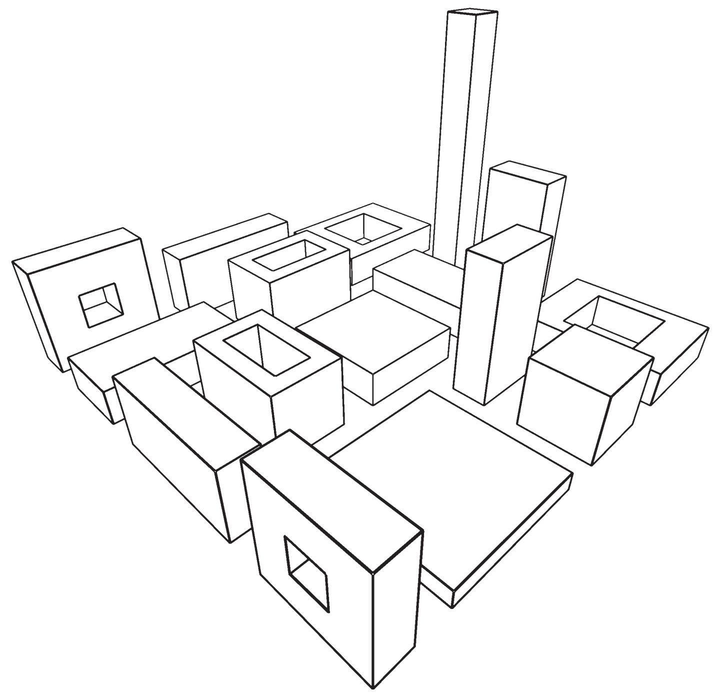


Fig. 139: Variety of architectural concepts for one building (the same floor area and the same volume)

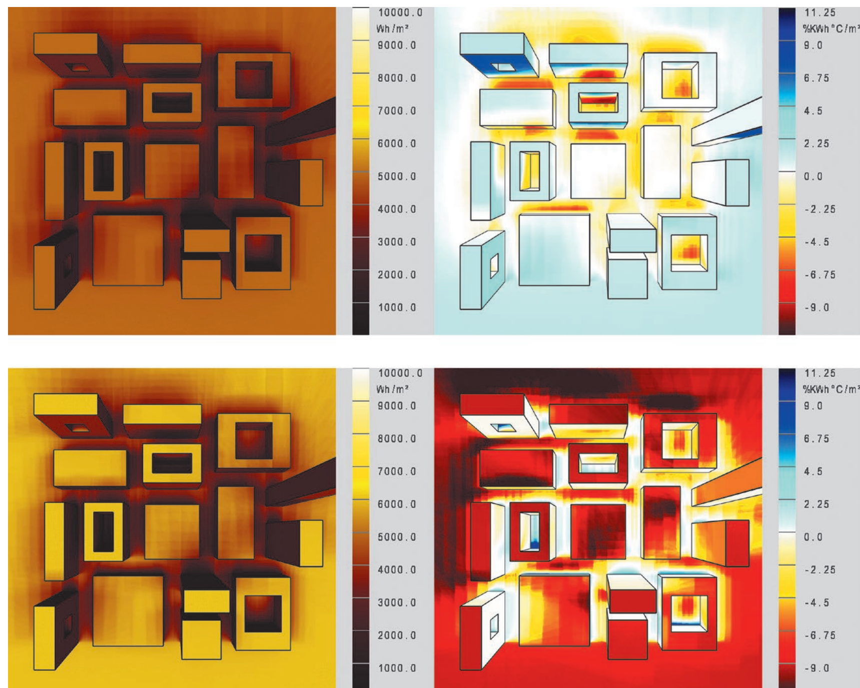


Fig. 140: Comparison of SOLARCHVISION models in two cities of Iran, left: active model, right: passive model, above: Tabriz (latitude: 38.0°N), below: Tabass (latitude: 33.5°N)

in the urban fabric should be studied simultaneously within a comprehensive analysis in order to optimize building shapes and orientations in regard of solar and climatic aspects. These processes are extremely important since the energy performance of other buildings and the comfort measures outdoors can be severely affected by a single building in an urban context for a long period of time. Meanwhile, an intelligent design always seeks to consider all aspects and people.

In this respect and in addition to mapping solar radiation on buildings and urban surfaces, the SOLARCHVISION analysis enables architects as well as urban planners to find out what the varied effect of the sun on each building's surfaces is and how architectural elements can help to improve the situation. In this way and by understanding the concept of the building skin, which is discussed in the section "Skin and climatic response", the basic analysis and optimization should be carried through at critical stages in the design. Further simulations should also be performed using other tools to improve different aspects of buildings and cities (e.g. detailed modeling with specified materials and HVAC systems).

In this chapter, the SOLARCHVISION spatial analysis and its application for the design optimization of the building skin and the architectural concept will be presented first. An advanced energy analysis using the "DesignBuilder" software tool is also performed to compare the situation between two case studies in Tehran. The first category includes simple, ordinary buildings; the second one includes the same buildings but with small changes as a result of a solar-climatic approach in the architectural design. Consequently, the necessity to pay attention to the sun is illustrated in connection with the building energy demand and internal comfort as well as active strategies, which are discussed in the previous chapters. Afterwards, the analysis of outdoor areas within basic urban fabrics will be presented and compared for three different climates including Abu Dhabi, Tehran and Montréal. Finally some solutions for improving the quality of these spaces (e.g. membrane structures, trees, etc.) will be studied and discussed.

The SOLARCHVISION passive models show the advantages and disadvantages of direct and diffuse solar radiation in relation to the buildings' geometries throughout a year or a limited period of time (e.g. in winter or from noon to sunset). The annual passive analysis in different cities of Iran, for instance, illustrates a remarkable difference between the various climates despite the radiation models being fairly similar.

In addition to the annual cycle radiation model, which shows the active potential for solar energy and daylight, the SOLARCHVISION passive model presents the solar-climatic performance of the building envelope and urban areas according to the positive and negative effects of the sun, which helps to identify the effect the climatic conditions of the site have on the building skin in indoor as well as outdoor areas. Such an analysis provides a new insight for architects, urban planners and landscape architects and enables them to examine the advantages and disadvantages of their decisions concerning the sun in connection with other climatic conditions for each site, namely the general patterns of changes in temperature during the year.

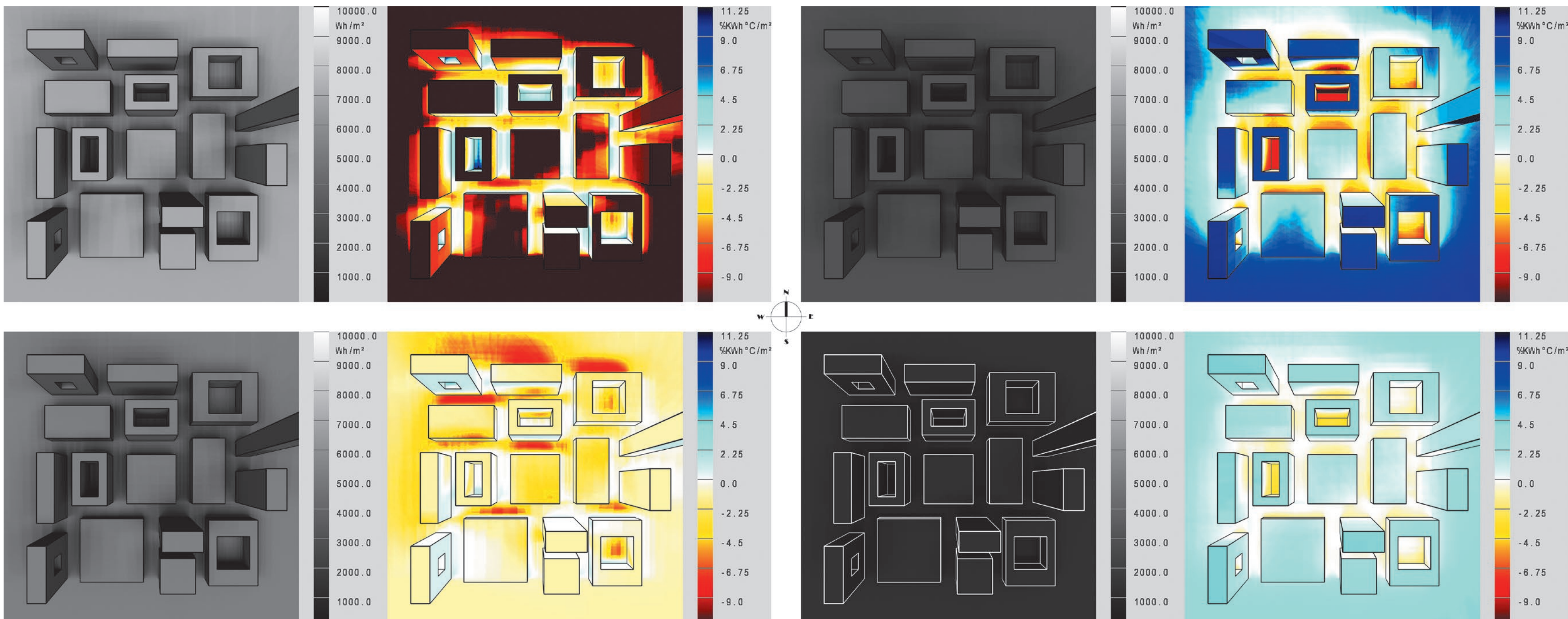


Fig. 141: Comparison of SOLARCHVISION models in different cities, left: active model, right: passive model, from top to bottom: Abu Dhabi, Tehran, Montréal, Munich

The SOLARCHVISION spatial analysis can be applied throughout the whole design process. Ranging from simple and basic models to detailed and complex ones, this analysis can help improve the design in regard of the quality of indoor and outdoor spaces in the built environment, at the same time as striving for a meaningful integrated design. In the SOLARCHVISION solar-climatic performance analysis (the passive models), the points are rated from red, which refers to the most negative performance, to blue, which indicates the most positive solar-climatic design performance. In addition, the middle-range values are displayed in colors of yellow, white and cyan. The graphs can also be used to determine the best position of windows and skylights in regard of improving the energy performance of the building envelope.

As the SOLARCHVISION passive model of Tabriz (Figure 140) presents, the solar-climatic performance of south and east-facing façades is high throughout the year. It would therefore be a wise decision to open these blue surfaces to the sun. The negative impacts the building geometries have on each other, as well as that on the urban area, especially east-west paths, have been plotted in red. On the other hand, for the case of Tabass, the solar-climatic performance of south and east-facing façades is still better than that of roofs; however, shading devices are essential in each of these directions to improve the solar-climatic performance from white to blue.

It is necessary to mention that in the SOLARCHVISION passive model, red does not mean hot and blue does not stand for cold! The red color

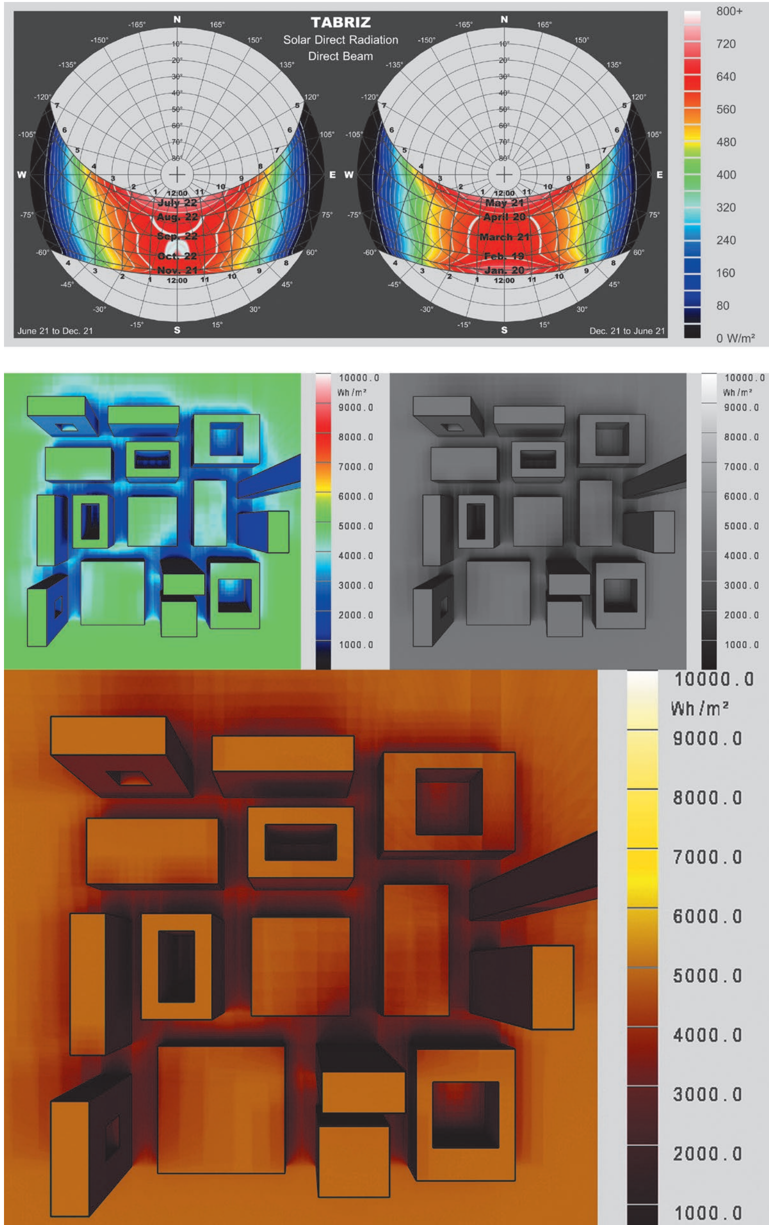


Fig. 142: General patterns of direct beam radiation (above) and annual total radiation models of Tabriz[1]

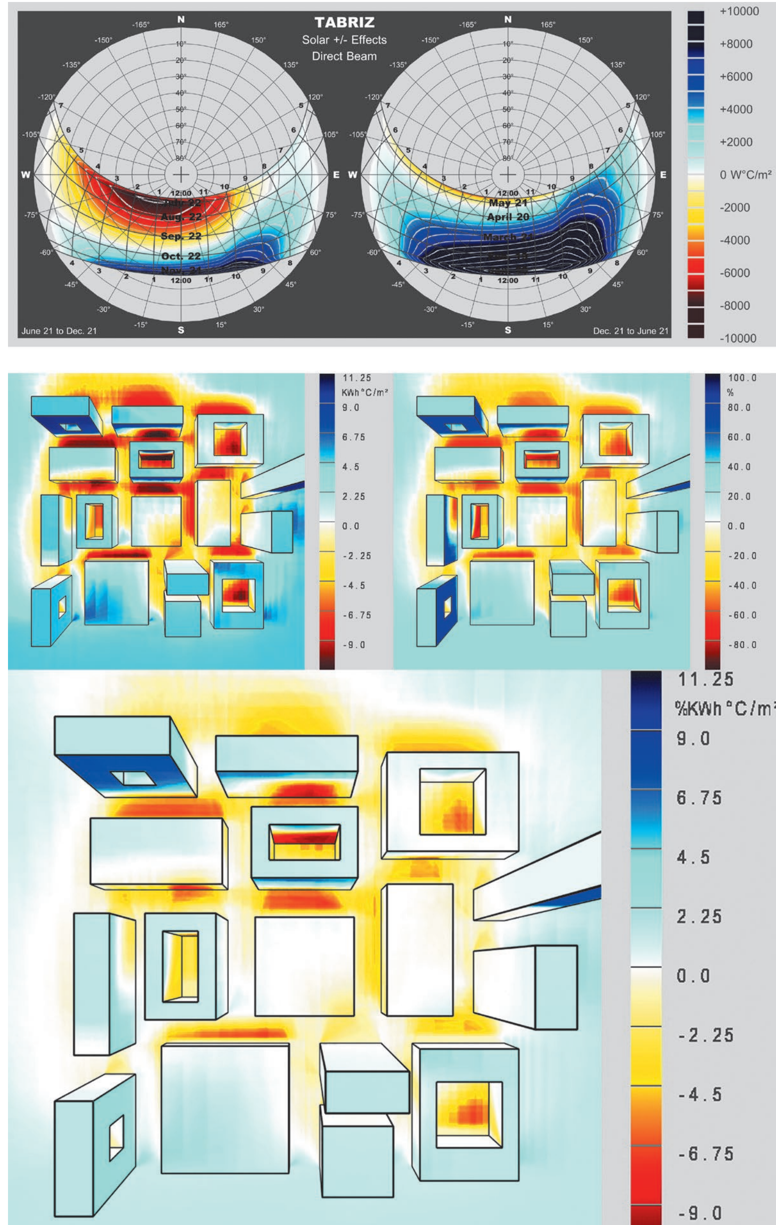


Fig. 143: General patterns of the positive and negative effects of direct beam radiation (above) and the SOLARCHVISION passive models for Tabriz[2]

presents a negative solar-climatic performance both in winter and summer. Therefore, red areas are subject to intense solar radiation during hot periods and are overshadowed in colder periods, as is the case for east-west-oriented paths. On the other hand, the blue color expresses a positive solar-climatic performance both in winter and summer. The blue areas are subject to intense solar radiation during cold periods and overshadowed during hot periods. The other colors, yellow, white and cyan, illustrate the areas which are desirable for only a proportion of the year. The performance of these middle-range and red areas can be improved by applying a variety of architectural, urban or landscape measures as is discussed in greater detail later in the chapter.

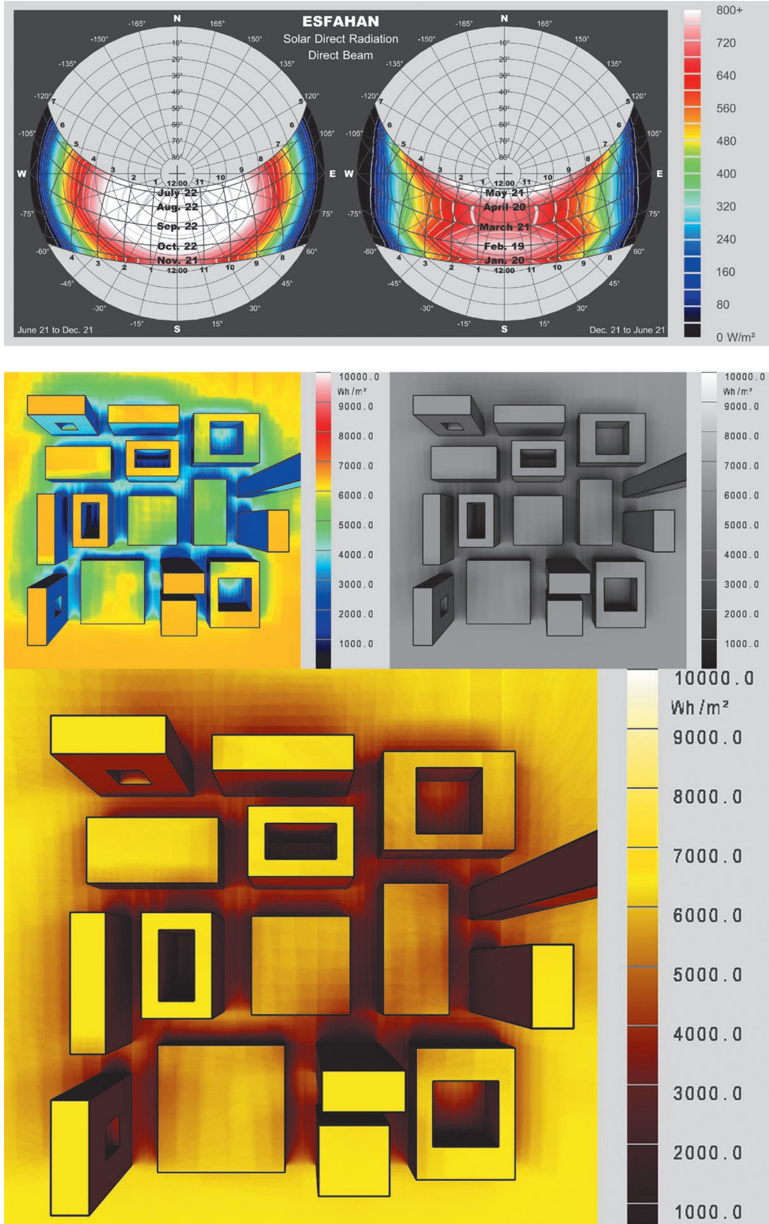


Fig. 144: General patterns of direct beam radiation (above) and annual total radiation models of Esfahan[1]

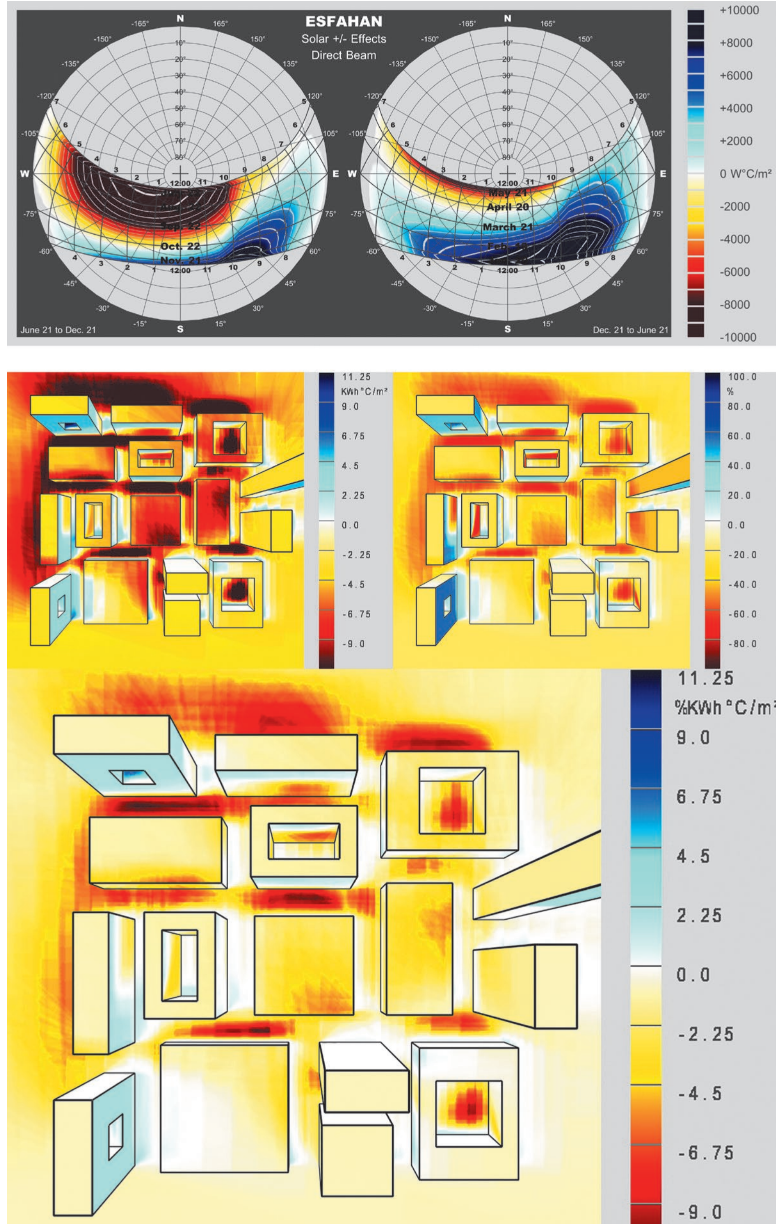


Fig. 145: General patterns of the positive and negative effects of direct beam radiation (above) and the SOLARCHVISION passive models for Esfahan[2]

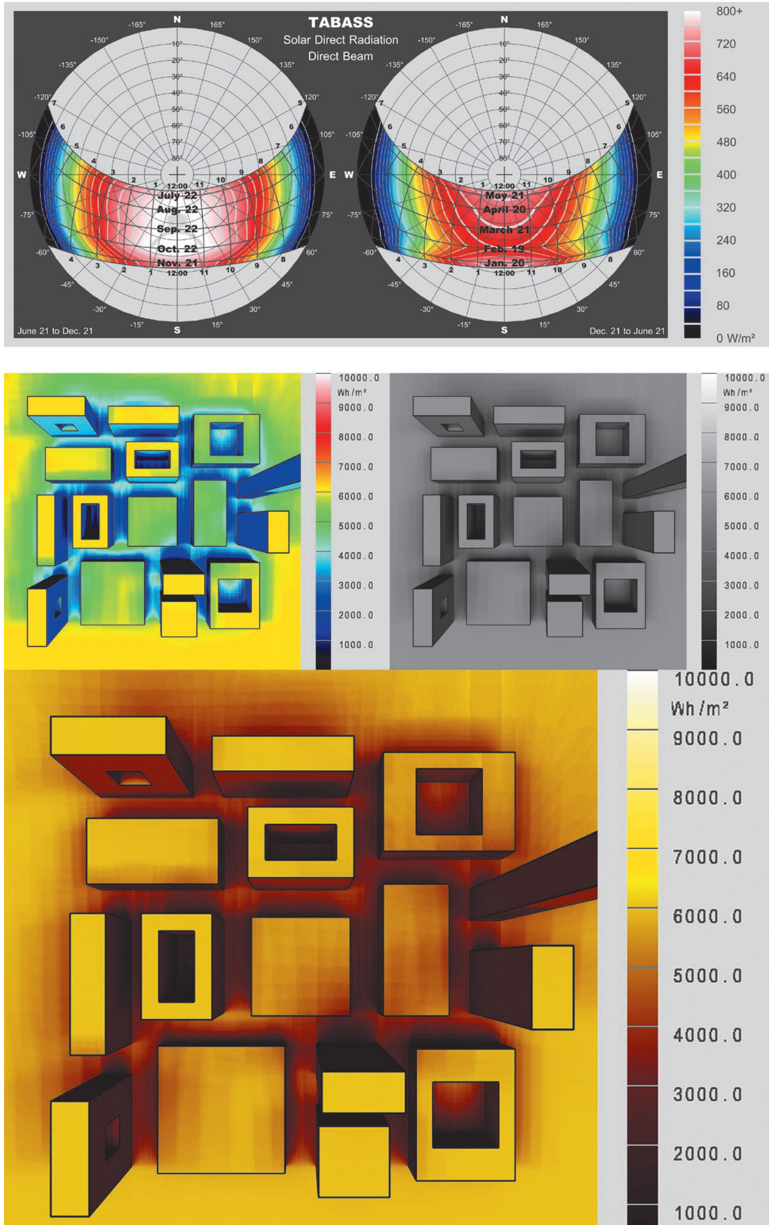


Fig. 146: General patterns of direct beam radiation (above) and the annual total radiation models of Tabass[1]

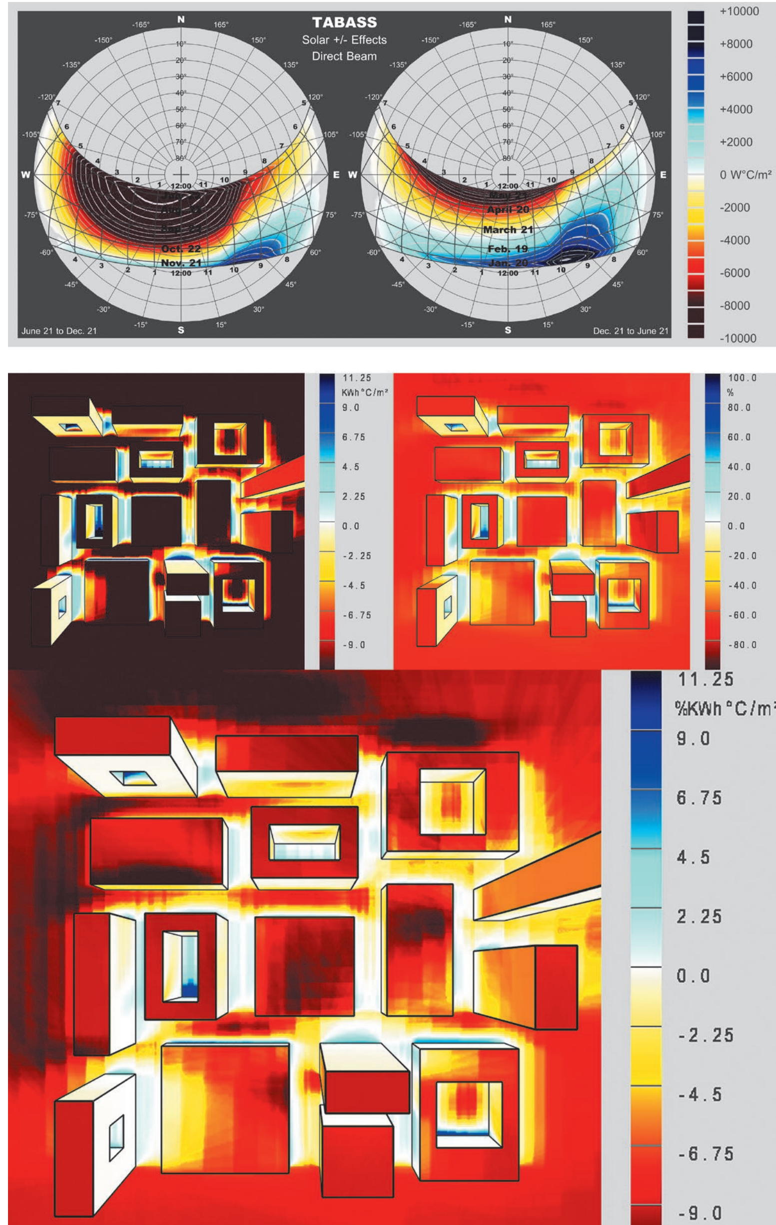


Fig. 147: General patterns of the positive and negative effects of direct beam radiation (above) and the SOLARCHVISION passive models for Tabass[2]

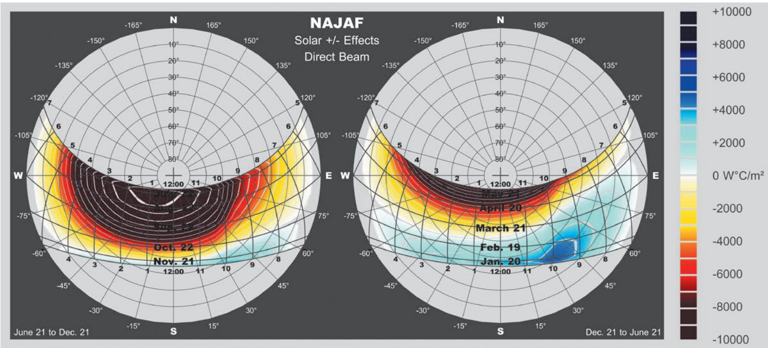


Fig. 148: General patterns of the positive and negative effects of direct beam radiation (above left)
Fig. 149–150: Najaf's traditional urban fabric and its annual cycle using the SOLARCHVISION analysis (Samimi, 2008)

In hot and sunny climates similar to Najaf (30 km south of Babylon) in Iraq, the negative effect of the sun is remarkable throughout the year. Therefore, in a passive approach, the general concept should be to increase the amount of shade in the openings of each direction and on the roofs as well as in the outdoor areas. However, this is not a simple task that can be accomplished easily without the integration of proper proportions within the urban fabric as well as elements in the building skin.

These unique relations cannot only be studied in Najaf and warm climates, but also in many cities around the world in relation to their original climatic aspects. In this way, the SOLARCHVISION analysis of the traditional urban fabric of Najaf in Iraq illustrates a notable positive solar-climatic performance as a result of the ingenious use of courtyards and paths throughout the year.

In addition to the architectural concept of courtyard houses, which is visible in plans, the positive performance of courtyards in Najaf is remarkably improved by increasing the scales in the z-axis to achieve deep courtyards in the sections (Figure 150). To better clarify this, the 2008/09 SOLARCHVISION analysis of the alternative solution for an extension to the western side of the Imam-Ali mosque is presented here which was developed in 2006 by the Technical & Research Department the west-east approach towards the dome. Therefore, membrane shading devices as well a change in the number and the layout of trees were proposed and developed carefully within the process of the design to improve the overall situation.

As the SOLARCHVISION analysis of trees in Figure 153 illustrates, the proposed layout for the trees creates effective shading for the paths on the north side (painted in blue); however, the red middle area shows

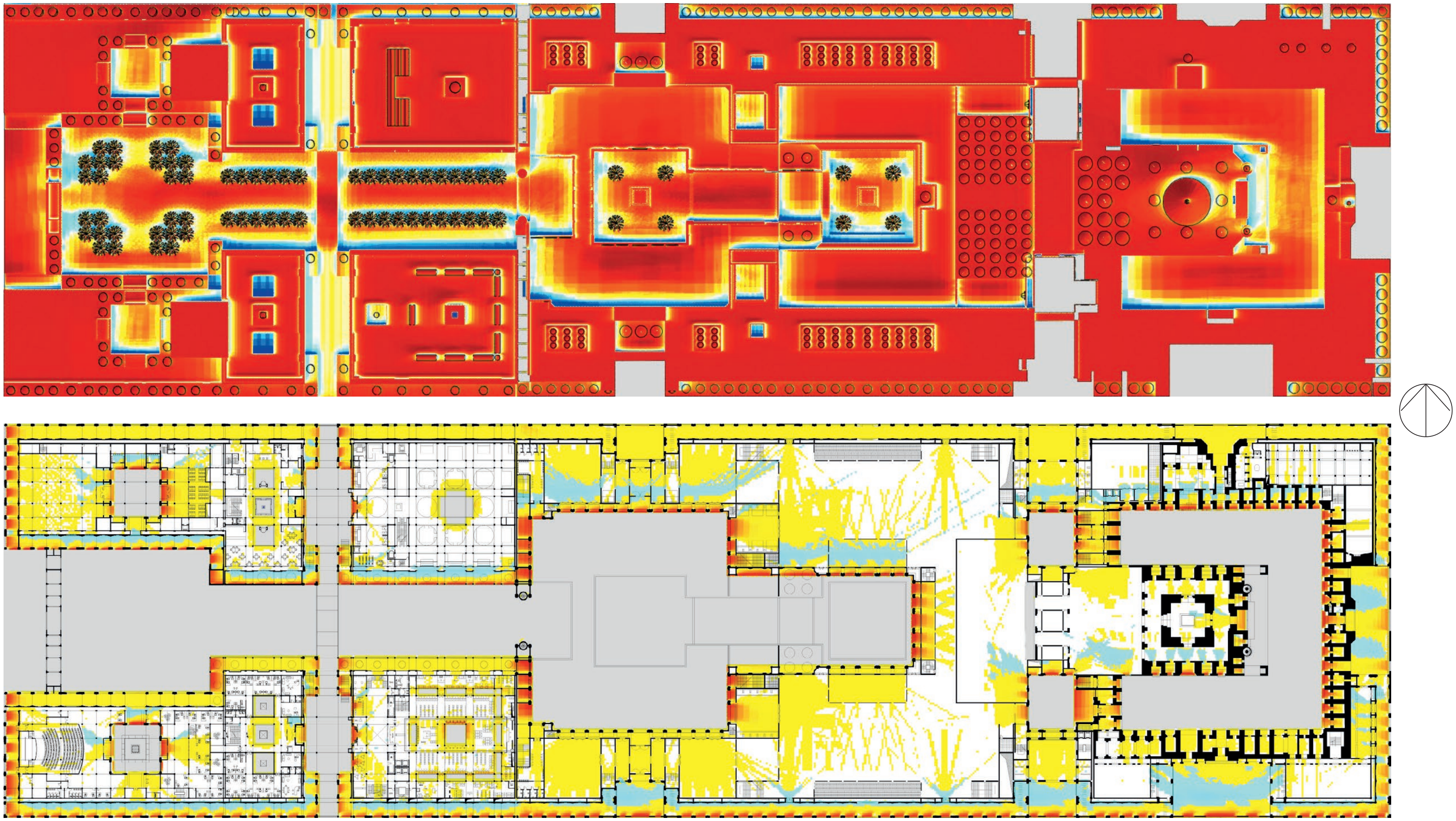


Fig. 151–152: Indoor and outdoor SOLARCHVISION analysis of SBU's developed alternative for the west extension of Najaf's shrine

in the faculty of architecture and urban planning at the Shahid Beheshti University (SBU) in Tehran. The outdoor solar-climatic performance analysis in Figure 151 illustrates the fact that the proportions of large courtyards cannot create a desirable situation during the annual cycle especially concerning the long entry path leading from west to east. On the other hand, one of the principle parameters in planning the whole complex was to minimize the interruption of the architectural form in insufficient shading for the axis of this path leading from west to east.

In contrast, the north/south-oriented paths feature better conditions than those in east-west-oriented paths (Figures 153–154). North/south-oriented paths have valuable shade for many hours during summer, except for a limited period around noon. Additionally, a north/south-oriented path receives more favorable solar radiation during winter days in comparison to an east/west-oriented path.

In addition to several aspects which should be considered in the design process of the building skin (e.g. visual, structural, safety, etc.), the design of shading and reflecting devices should be intelligent enough to function properly in both warm and cold situations in regard to the varied position of the sun in the sky as well as the positive and negative effects of direct and diffuse radiation in each location. Considering the complexity and importance of shading control in each direction (e.g. roof, west, south, east, north, etc.), comprehensive studies should be carried through during the design and modification of future and existing buildings incorporating historical solar-climatic data and forecast scenarios. In regard to the proven role of external shading devices in reducing the building's energy demand, the solar-climatic performance of different façades is analyzed and different variations for improving the solar-climatic performance of each orientation are studied using the SOLARCHVISION basic and spatial analysis.

Returning to the case study of Najaf, the SOLARCHVISION analysis of the south façade (Figure 154) illustrates the correct design for this area as it is in the blue range. That is because sufficient depth is given in the arcade of this orientation protecting the building skin against unfavorable solar radiation throughout the year. Moreover, it produces comfortable outdoor areas for pedestrians.

The solar-climatic performance analysis of the east and west façades (Figure 155) also demonstrates that depth produces the right effects in

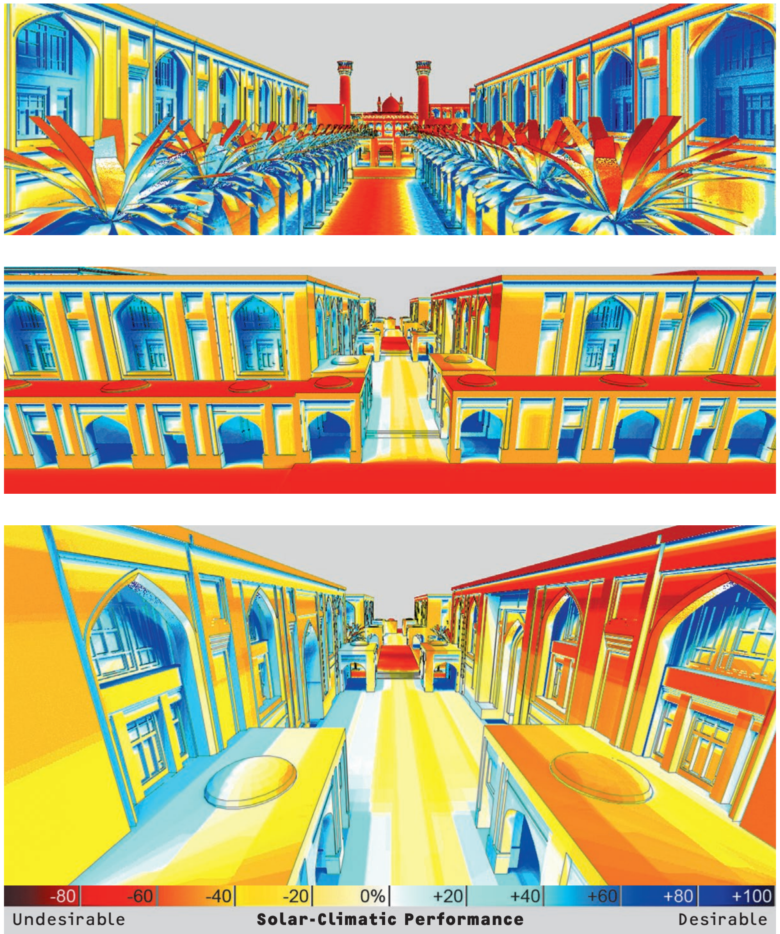


Fig. 153–155: SOLARCHVISION analysis of different façades for the extension project in Najaf (above: west/east-oriented path as well as the north and south-facing façades, middle: south, below: east and west)

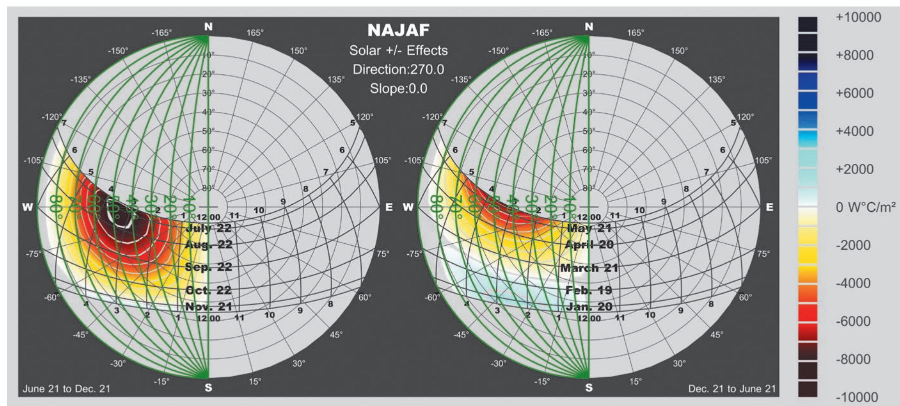


Fig. 156: Positive and negative effects of direct radiation on the west façade in Najaf

some parts of the windows as is highlighted in blue. However, there is not sufficient depth in these two façades. Meanwhile to protect the building skin (windows) against undesirable solar radiation throughout the year, the façades should be optimized either by repeating the processes of 3D-modelling and using the SOLARCHVISION spatial analysis or simply by using the basic SOLARCHVISION diagrams within the design process. Basic diagrams of the positive and negative effects of direct radiation on different façades (e.g. west) can be applied to determine the proper proportion of shading devices in the first steps of the design (Figure 155).

By using the green mask in each orientation, which measures the "Vertical Shadow Angle" in the diagrams, the architect can determine the proportions of horizontal shading devices to help protect the façade from unwanted solar energy during certain times of the year. As an example, in the case of the diagram of Najaf's positive and negative effects of direct radiation on the western façade in Figure 153, horizontal shading devices are required with a depth and height ratio equal to the tangent angle of 70° (Depth/Height > 2). For the south and east directions in Najaf, this value should be 45º, which means that the depth and height of the horizontal shading devices is equal.

The diagrams of Figure 157 introduce different angles which can be read by different masks in regard to the position of the sun in the sky. The left diagrams show how to read the azimuth and altitude of the sun on an Equidistant Sun Path. For instance, the altitude angle of the sun for the position illustrated is 50° and the azimuth angle is -30° (S.W.). The middle diagrams show how to read the angle of incidence for a particular vertical plane (wall or window) which is oriented toward +30° (S.E.). There is a relation between the cosine of the angle of incidence and the amount of direct solar radiation received on each surface. Finally, the diagrams on the right show the horizontal and vertical shadow angles for the same vertical plane. These angles can be applied to determine which angle is required for horizontal or vertical shading devices to create full overshadowing of that specific window at that specific position of the sun.

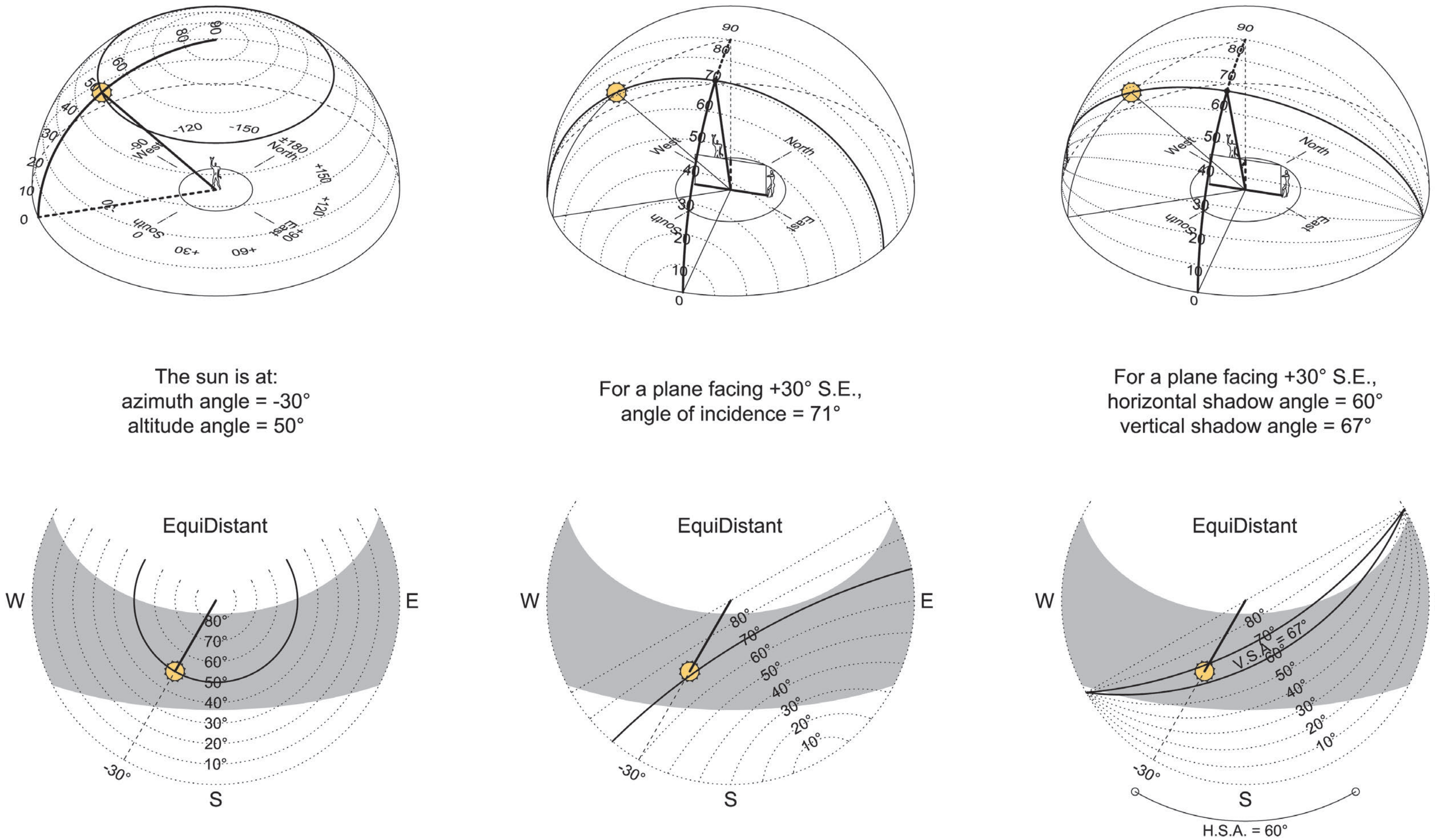


Fig. 157: Masks for measuring the Azimuth and Altitude of the sun, Angle of Incidence, H.S.A. (Horizontal Shadow Angle) and V.S.A. (Vertical Shadow Angle) on equidistant sun paths

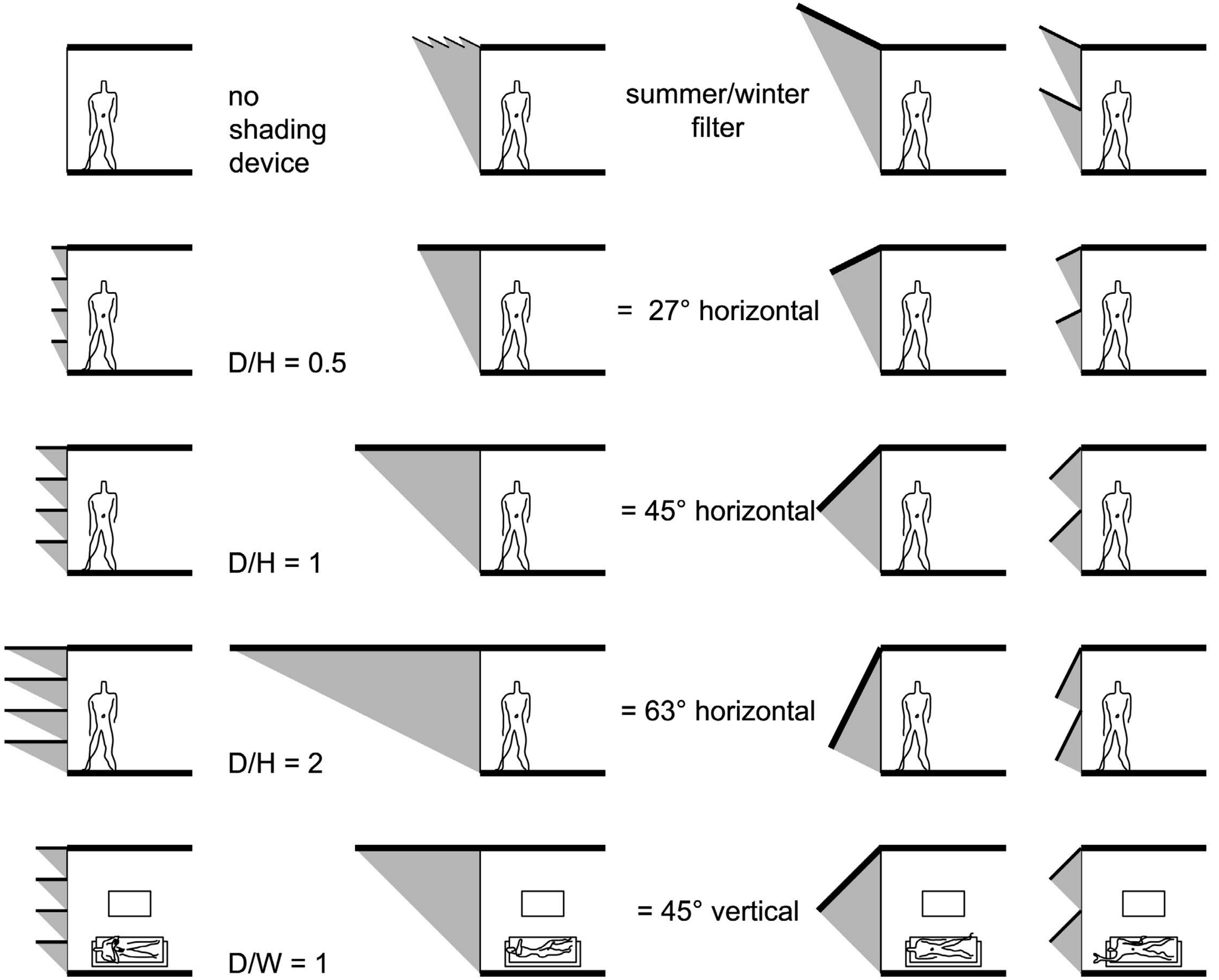
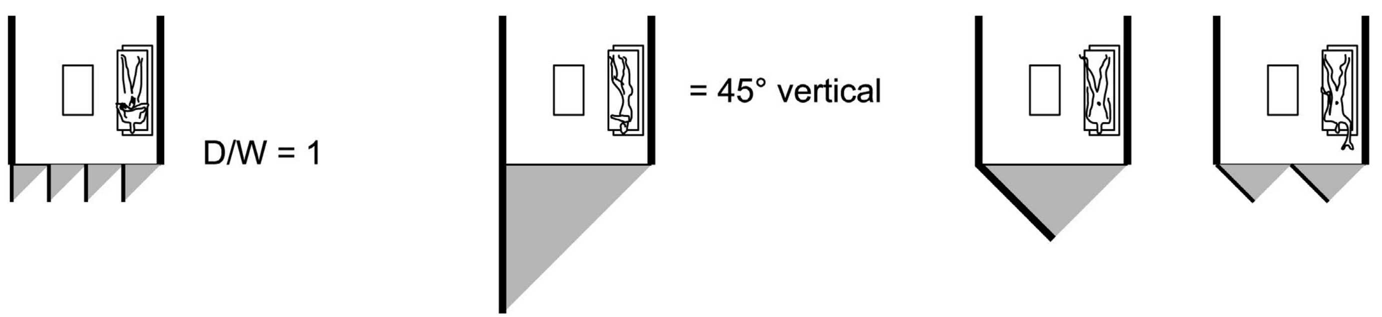


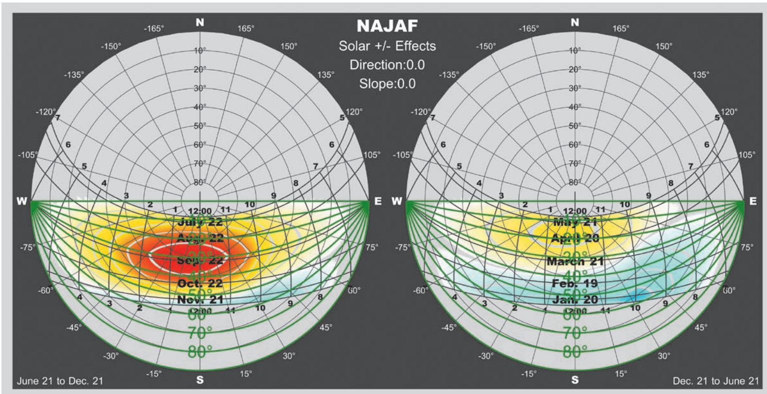
Fig. 158: Basic horizontal and vertical devices and the definition of their proportions in relation to the depths or angles (two lower rows present the plans for west and south façades)

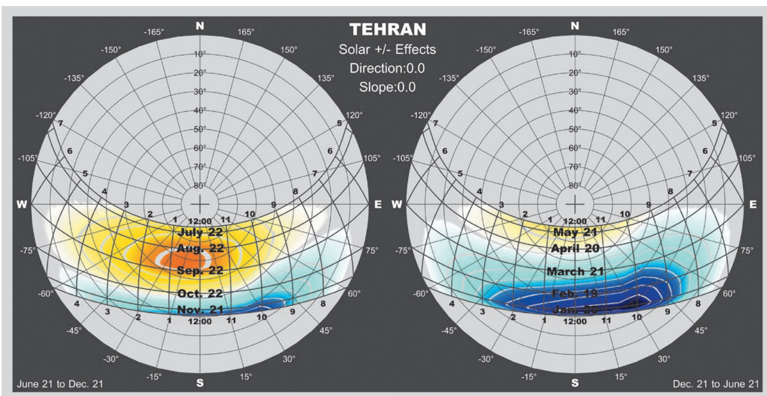


In contrast to general belief, the lower altitudes of the sun in hot periods (e.g. summer and autumn) must also be considered in the process of building design and urban planning. Taking the example of a south (or south-west or south-east) oriented façade (in the northern hemisphere), the negative effect of the sun on the south façade does not reach a maximum on 21 June. That is simply because the altitude of the sun is so high in the warmest months of the year, e.g. May, June and July, that the negative effect of the sun for the south direction reaches its maximum in other months of the year, between August and October and notably in September (Figure 159–160). Consequently, it is not recommended to carry out the performance analysis and adjust the design on the longest or warmest day of the year. As is discussed earlier, the date of the most critical as well as the most extreme conditions for each building's façade orientation and inclination must be studied carefully. The basic SOLARCHVISION analysis can help considerably towards finding the best architectural solution in design and planning.

On the other hand, unlike in warm climates, shading devices can reduce the performance of the building skin at times when the outside temperature is low. Direct solar radiation can be used to provide free energy, increasing the indoor temperature to comfort levels. In this respect it must be noted that using the profile angle of the sun on 21 December at noon (e.g. 30° for Tehran) to control undesirable shading effects on the building skin as well as overshadowing of neighboring buildings and open areas may not be ideal because the sun has lower or higher altitudes at other hours during winter. As a result, a range of profile angles (e.g. from 25° to 50° for Tehran) are more suitable for this process.

For Tehran and similar cities with cold winters, vertical fixed shading devices are not advisable due to their severe ineffectiveness in the heating period and their ineffectiveness in the cooling period. Horizontal shading devices facing south in Tehran (as well as a number of cities located in the northern hemisphere) can protect the building skin from undesirable radiation in summer during the cooling period. However, in consideration of the high altitude of the sun in summer, a horizontal surface with a small depth can produce a large amount of shade on the south surface of the building. On the other hand, horizontal surfaces can also produce undesirable overshadowing in winter. It is therefore not ideal to use dense, fixed horizontal shading devices in south façades in front of the windows.





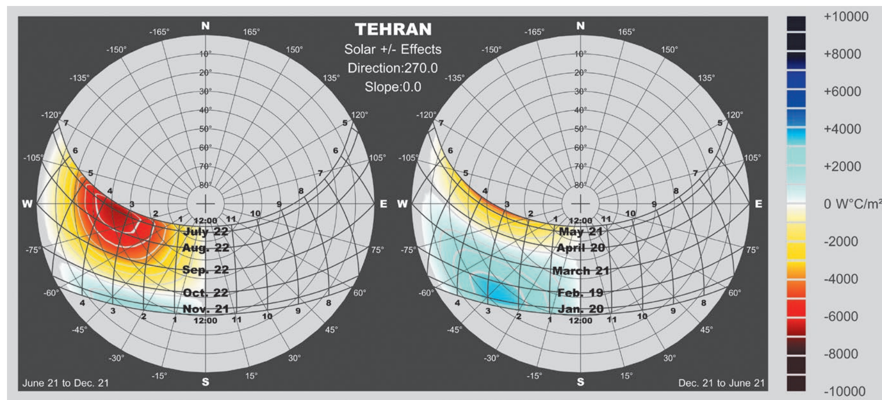


Fig. 159: Positive and negative effects of direct radiation on south façade in Najaf | Fig. 160: Positive and negative effects of direct radiation on south façade in Tehran

Fig. 161: Positive and negative effects of direct radiation on west façade in Tehran

There are a number of practical solutions which can be designed and presented with the help of a section. In this respect, intelligent alternatives of fixed horizontal shading devices for south façades can be developed using the idea of upward-tilted horizontal planes which allow winter rays to penetrate the building skin. A reversed tilted surface below the window can reflect the winter rays into the building. Figure 162 presents the studies of some alternatives for shading/reflective devices in a south façade. As was discussed earlier, there are a variety of profile angles which can be considered in the design process in regard to the sun path, the climate as well as the façade orientation.

Another way to decrease the negative effects of horizontal shading devices in cold periods is to use upward-tilted louvers. In this case, the gaps between the louvers let in the winter rays from the south and prevent them from penetrating during hot periods. This method can be used for a wide range of orientations from east to south and from south to west. It also improves natural daylight performance in the building as well as outdoors.

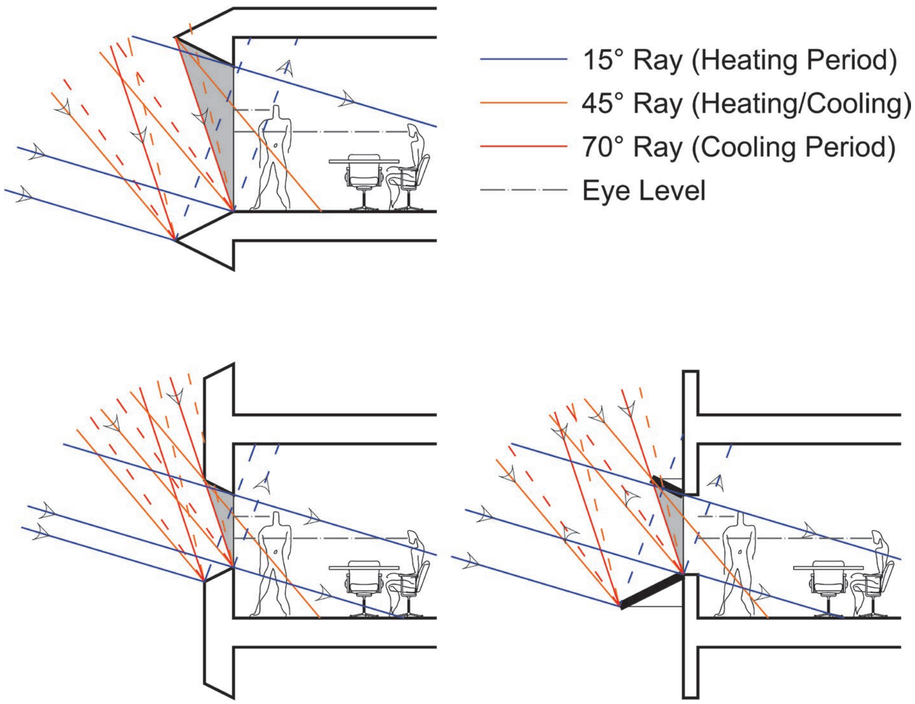


Fig. 162: Study of shading and reflective devices for a south façade in Tehran

Taking the example of the complex climate of Tehran, which has both cold and warm situations during the year, further diagrams illustrate some basic studies of different proportions of horizontal and vertical shading devices. The study is designed to present different variations as well as their performance using the SOLARCHVISION analysis for the building skin. By comparing the annual cycle results of each direction, the best types and proportions of fixed shading devices are easily identified, which perform well during both cold and warm conditions. On the other hand, the selected alternatives can also be improved and customized to the project's needs by applying the advanced SOLARCHVISION analysis as well as a solar-climatic vision in the design. It is necessary to mention that the results presented here can generally be used for true south and west directions in Tehran. Further analyses are required for other directions and cities.

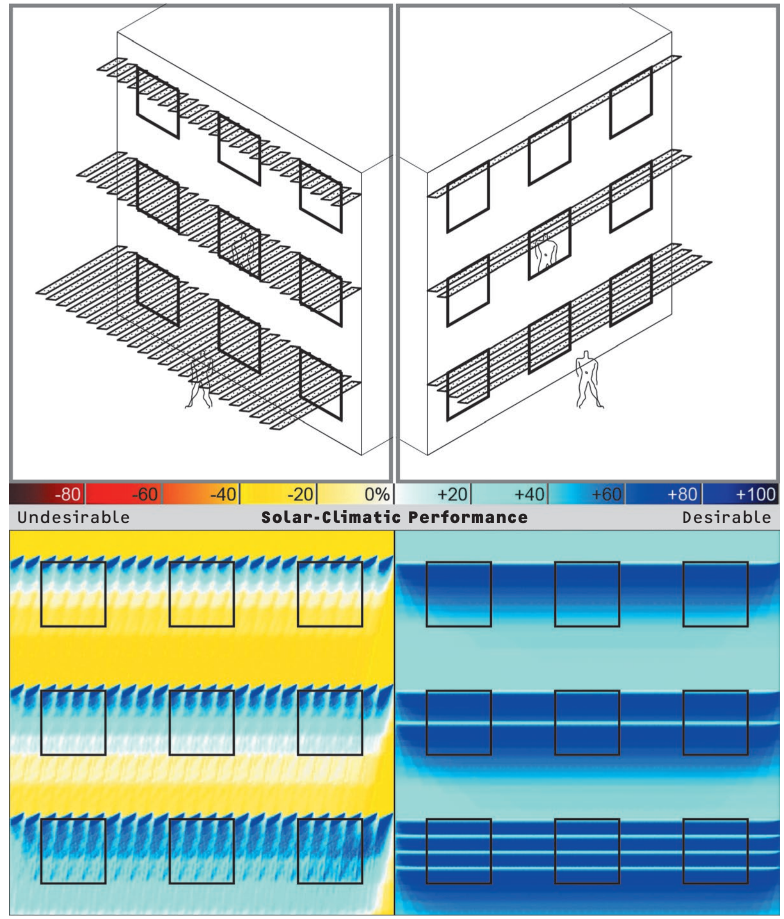


Fig. 163: Upward-tilted louvers for west and south orientations and the SOLARCHVISION performance analysis

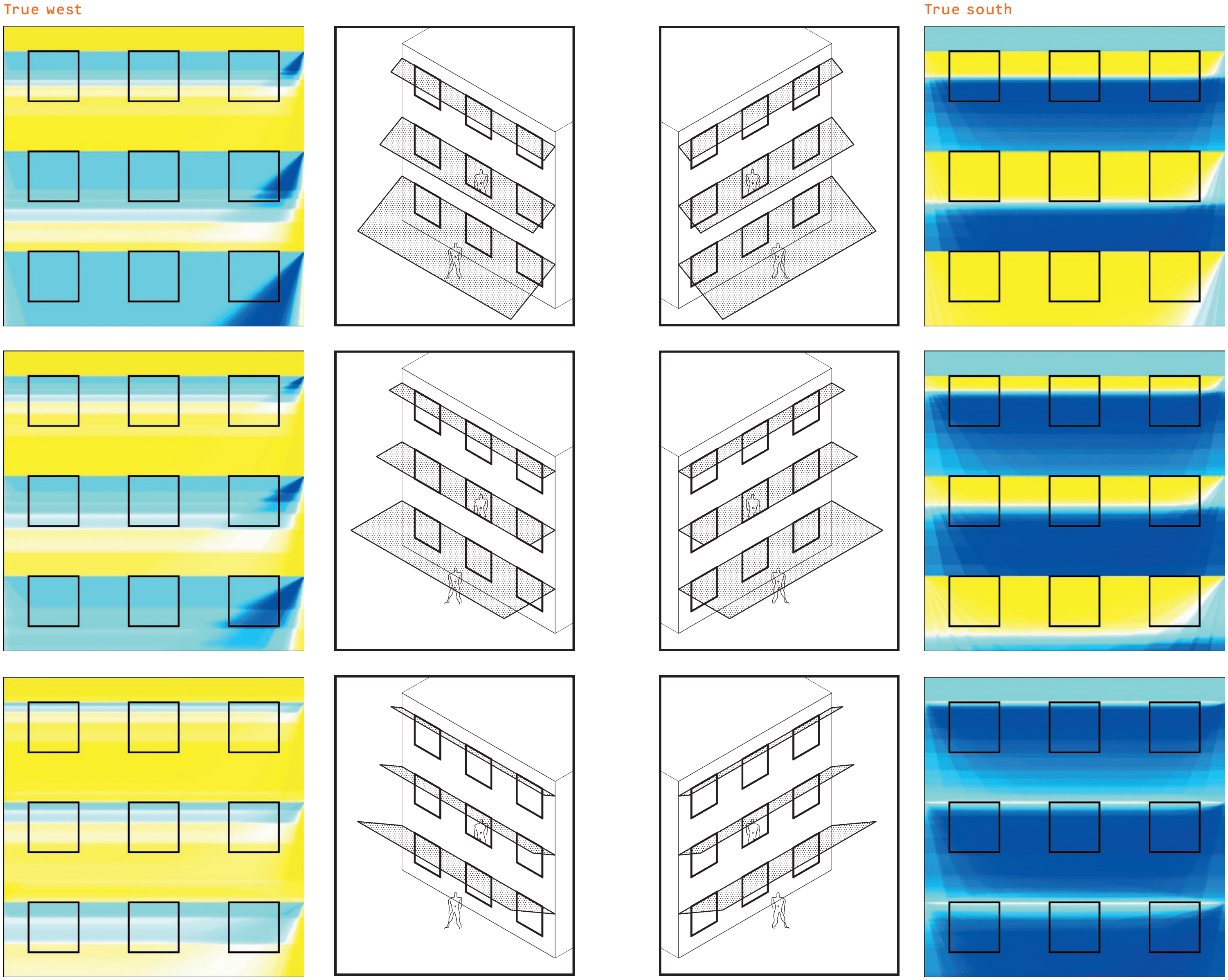
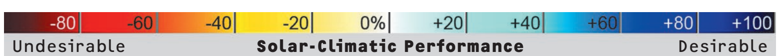


Fig. 164: SOLARCHVISION performance analysis for a variety of horizontal shading devices in west and south orientations during the annual cycle



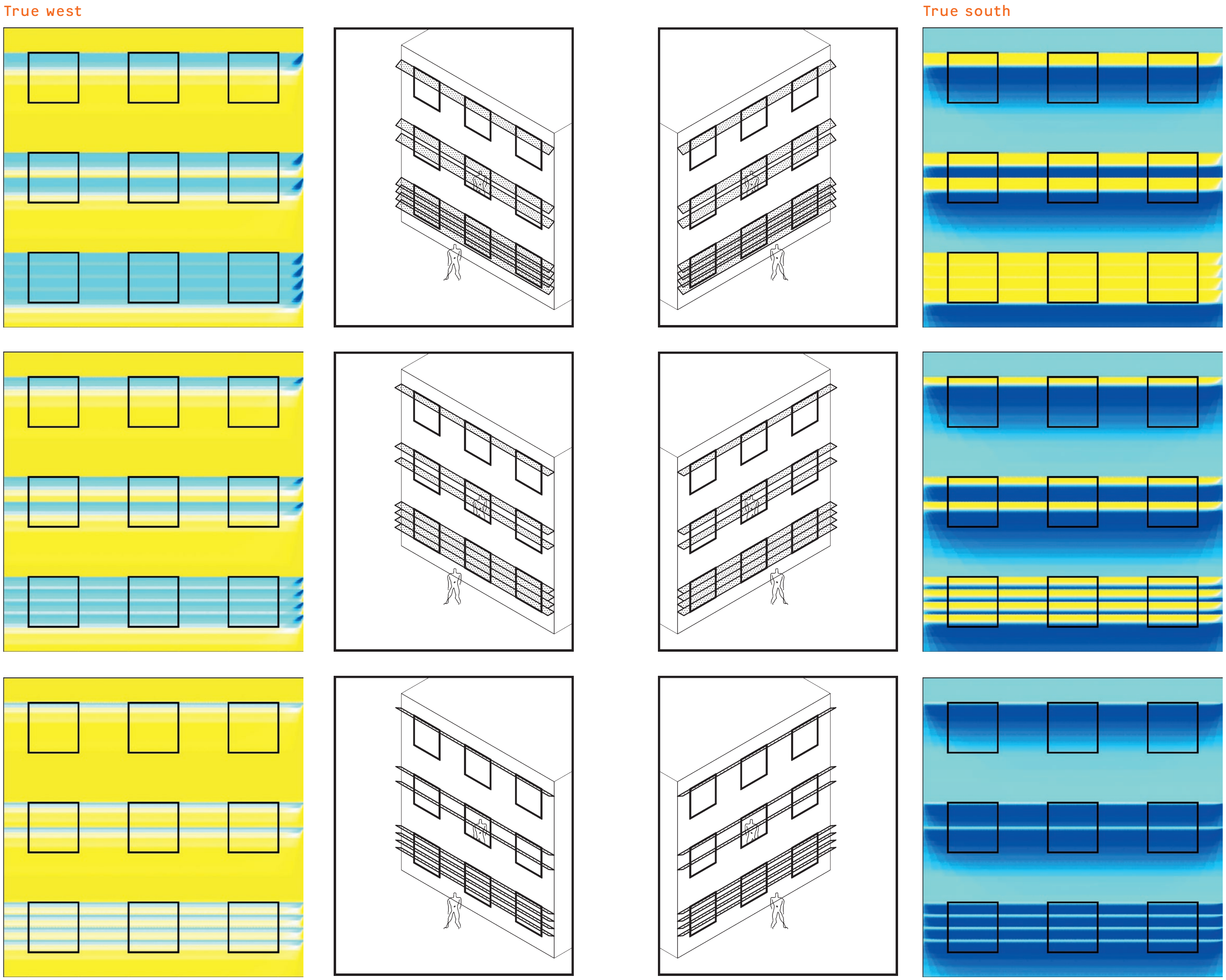
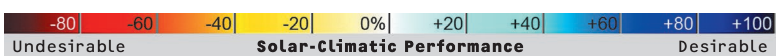


Fig. 165: SOLARCHVISION performance analysis for a variety of horizontal shading devices in west and south orientations during the annual cycle



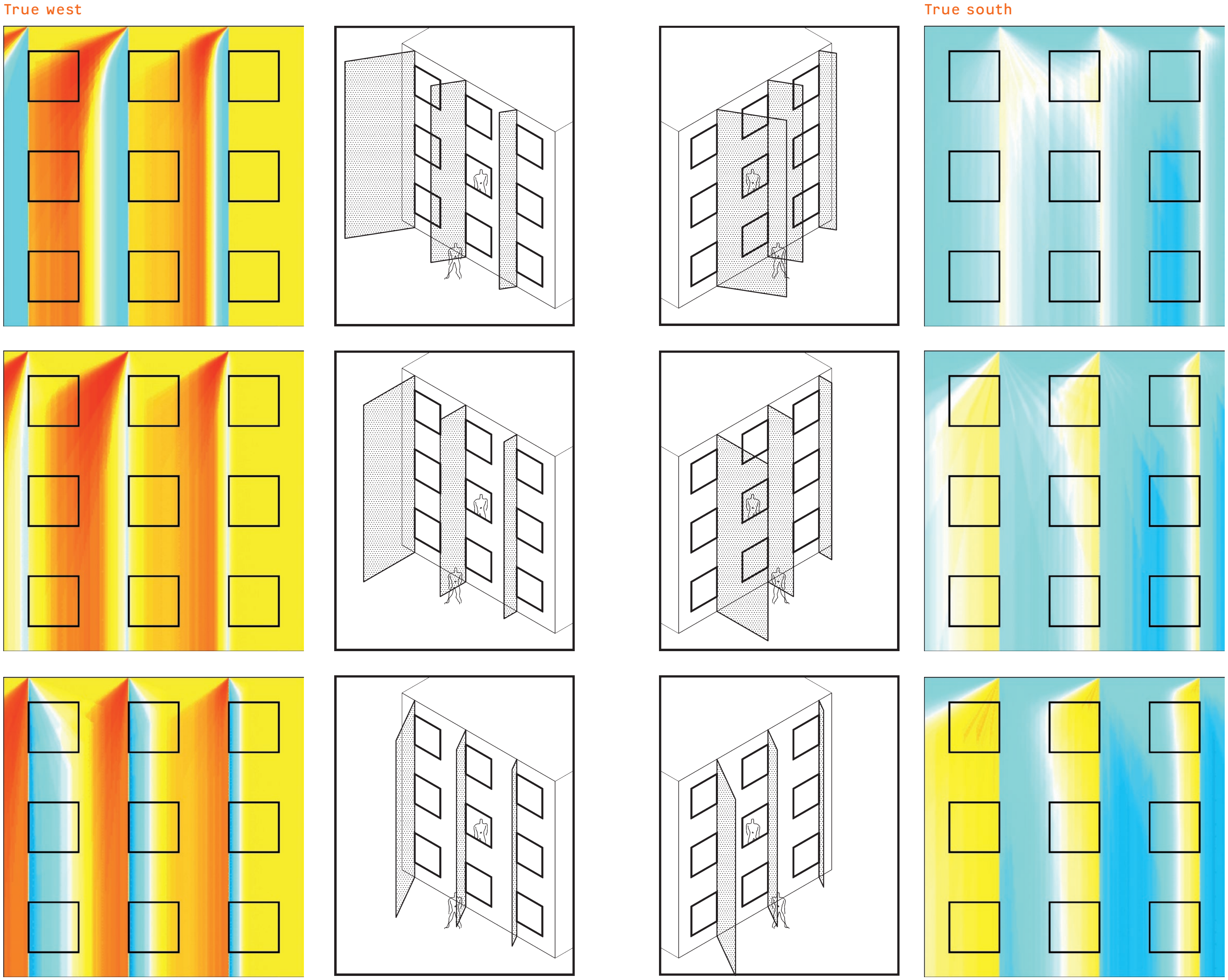
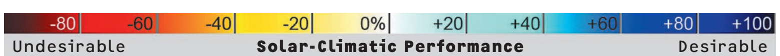


Fig. 166: SOLARCHVISION performance analysis for a variety of vertical shading devices in west and south orientations during the annual cycle



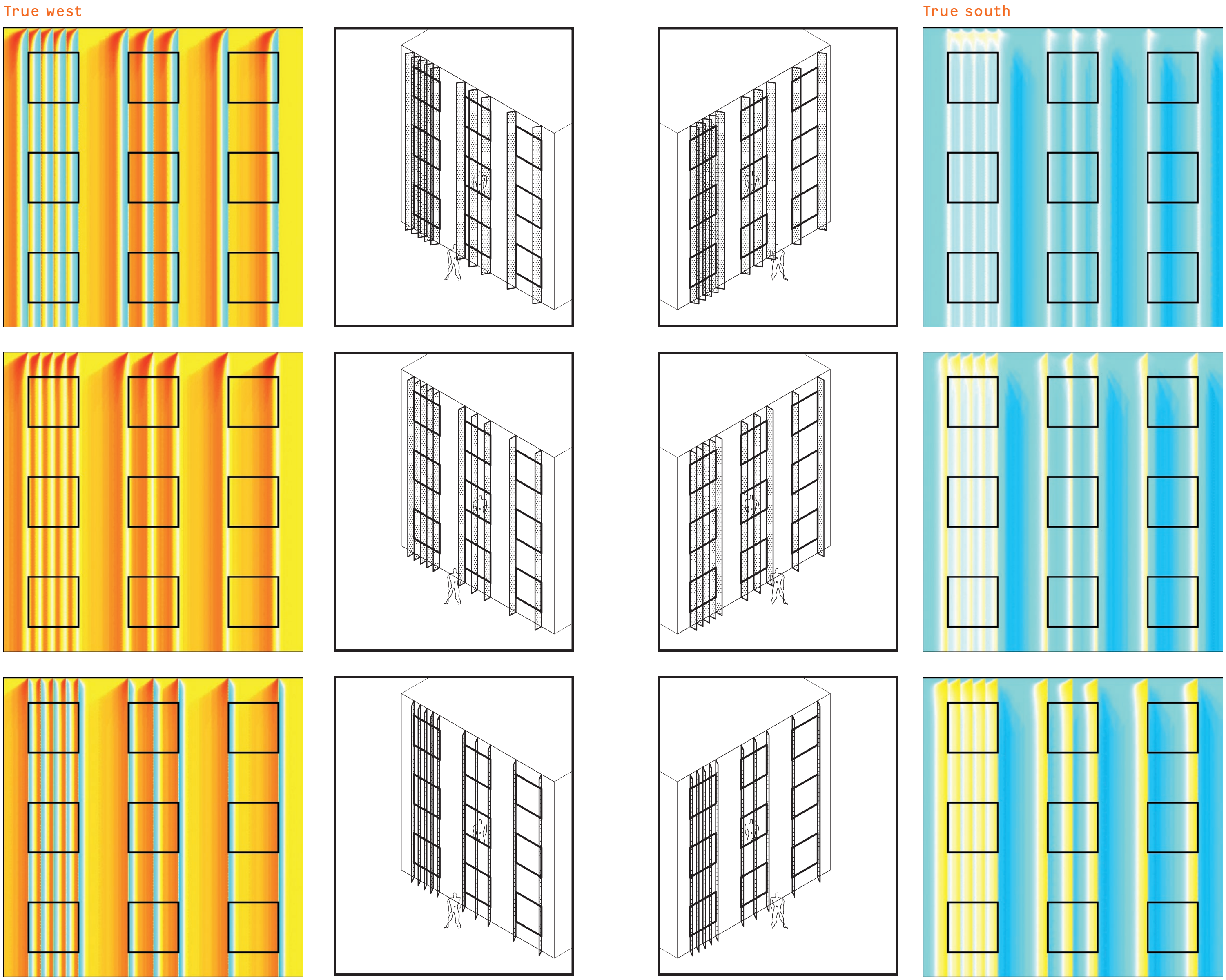
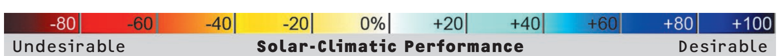


Fig. 167: SOLARCHVISION performance analysis for a variety of vertical shading devices in west and south orientations during the annual cycle



In contrast to general belief, that fixed vertical shading devices are suitable for east and west directions, the analyses show low performance of these elements in regard to the varied sun positions in Tehran as well a number of other locations around the world. This is simply because they cannot block out the sun effectively for many hours during the day, especially in hot periods when the sun is at a high or average altitude. Moreover, they produce a lot of undesirable shade in winter when there is performance in the interior. To improve the situation they can be replaced by upward-tilted, horizontal louvers (toward the south) to perform better in terms of energy efficiency and daylight throughout the year (Figures 161–166).

Similar architectural strategies can be identified using solar-climatic vision in the design, which can be optimized for different climates using the SOLARCHVISION analysis. In addition to the remarkable impact on energy savings and human comfort, a harmonious relationship between the architectural design of the building skin and the solar-climatic situation at each location can improve the window layout in each orientation as well as the shape of buildings in future. As is discussed earlier, a solar-climatic optimized fixed shading/reflecting device can benefit the building skin as well as internal comfort and energy efficiency aspects. On the other hand, in some cases, the development of movable shading/reflecting devices is another approach to achieve greater control on all variable conditions outside affecting the interiors.

For example, in an open office, the situation for occupants near the south façade is severely affected by energy and exposure of the sun, especially when the winter sun shines on to the building skin and enters the space. To solve this complex problem, one may suggest using internal louvers and curtains. However, this solution reduces visual comfort and daylight aspects in the interior. Bearing in mind that in most offices the internal heat gains through electrical devices and people are high, in both cold and hot periods of the year, solar heat gains are not desirable. An integrated approach in the design therefore seeks to completely block out direct radiation during the day while providing maximum daylight and views to the outside. In this respect, an external rotating vertical shading device can achieve outstanding results in terms of energy efficiency and daylight performance throughout the year. This intelligent system adapts by rotating around the Z-axis in relation to the position of the sun on sunny days; it can be applied in any direction ranging from south to west or east. Dynamic internal and external views, on the other hand, can create a variety of solar-friendly patterns during the day as well as iconic ones during the night. To improve visual and daylight aspects, in addition to aluminum, wood and PVCs, the whole or some parts of the system can also be made of fabric or other translucent materials (Figures 170–171).

A similar concept can also be used to improve the performance of roof PVs (or thermal collectors) by capturing direct solar radiation at

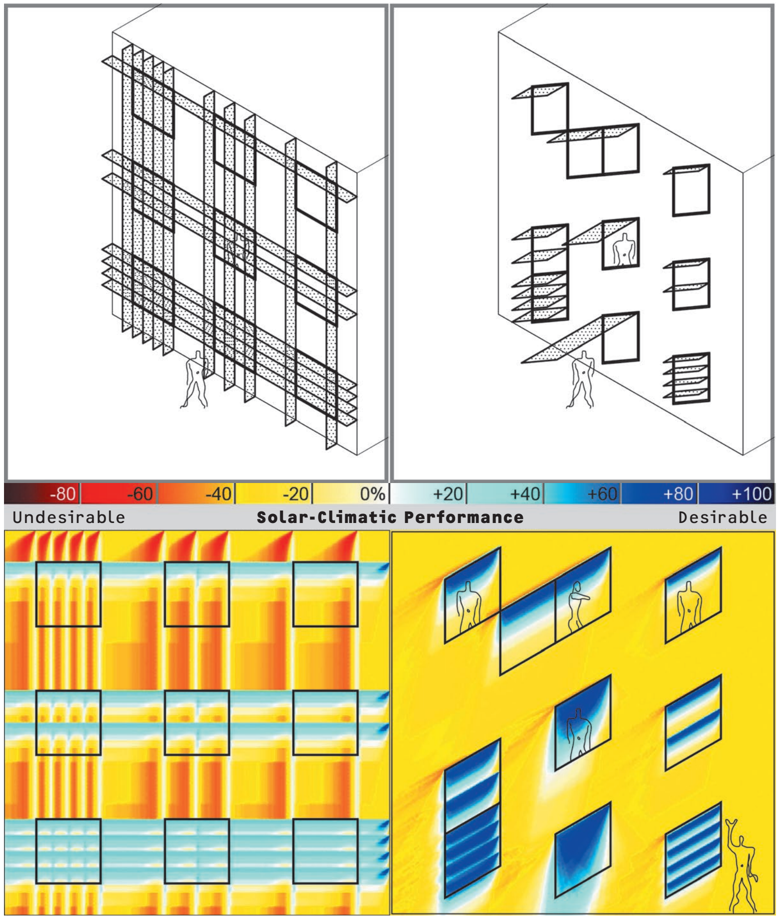
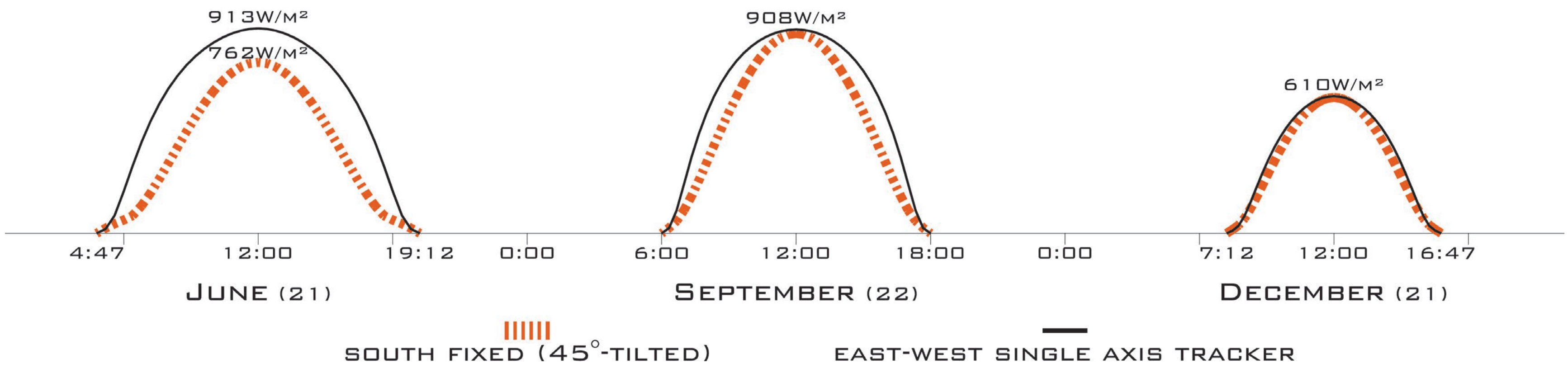


Fig. 168: Comparison of the form and performance of two alternatives for a west façade in Tehran, left: classical horizontal and vertical shading devices and square grid for windows, right: solar-climatic optimized devices and lozenge grid for windows

a need for solar energy. (Fixed vertical shading devices are better suited for south-east, south-west, north-west, north directions.)

In regard to the analysis of the west direction, with a variety of classical alternatives as presented in Figures 164–167, deep and dense horizontal shading devices perform better in Tehran. They support the building skin during the cooling period, but reduce the desirable solar gains in the heating period. They also have a negative effect on the natural daylight times when it is most needed in the office (mornings and afternoons), using practical ideas of daily rotation around the north/south axis (Figures 169–170).

In addition to what is discussed in section 2.2 about the importance of producing electrical energy at the time when it is required most to reduce the peaks in the city's electrical network, the layout of rotating PVs (or solar thermal collectors), as is illustrated here, provides more surfaces



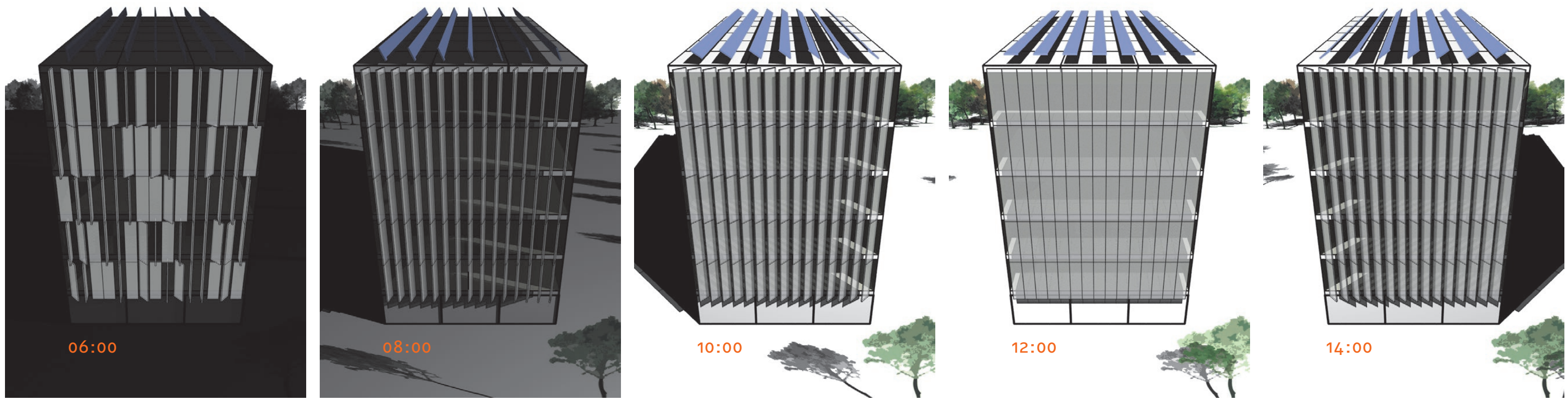


Fig. 169: Comparison of the amount of total (direct and diffuse) solar radiation received on one square meter of two alternative façades in different seasons in Tehran, orange: ordinary fixed south-oriented system (tilted 45°), gray: vertical single-axis tracker system | Fig. 170: Vertical external rotating shading devices for a south façade and a vertical single-axis tracker PV roof system (axis of rotation: south-north)

that can be used to capture solar energy. That is simply because in a vertical single-axis tracker system a smaller distance is required between the rows in comparison to an ordinary fixed south-oriented system (e.g. tilted 45°). In other words, less area is used to produce the required energy and more roof area is available for other functions (or to produce more energy). It is also worth noting that SOLARCHVISION studies on the optimization of vertical single-axis tracker systems demonstrate that the performance of these systems can also be improved in countries with higher latitudes (e.g. Europe and Canada) if the axis of rotation is slightly (e.g. 15°) tilted south (e.g. installation on sloped roofs).

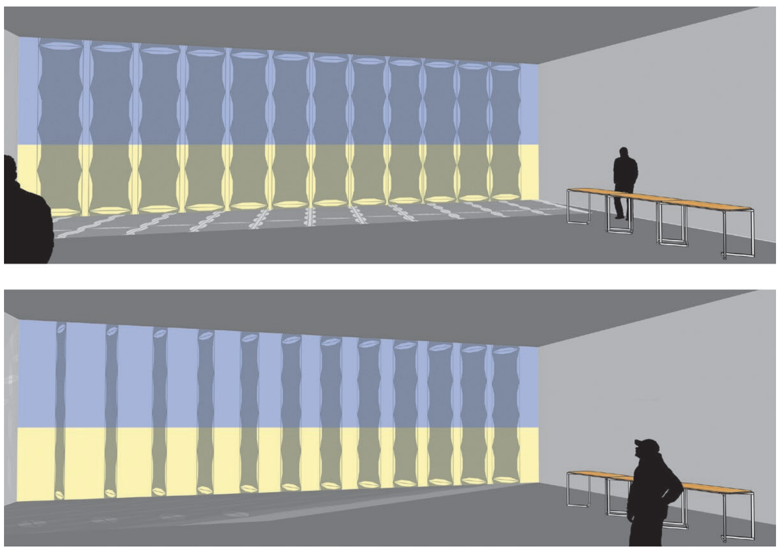
In addition to the solar-climatic improvement of windows in different orientations (e.g. south, west, etc.), the architectural design of roofs and their modification in relation to the sun is also an important area of design research. Whether roofs are designed to provide direct or indirect daylight for spaces inside buildings or not, they receive large amounts of solar energy during the day which can be used to increase the indoor temperature at certain times.

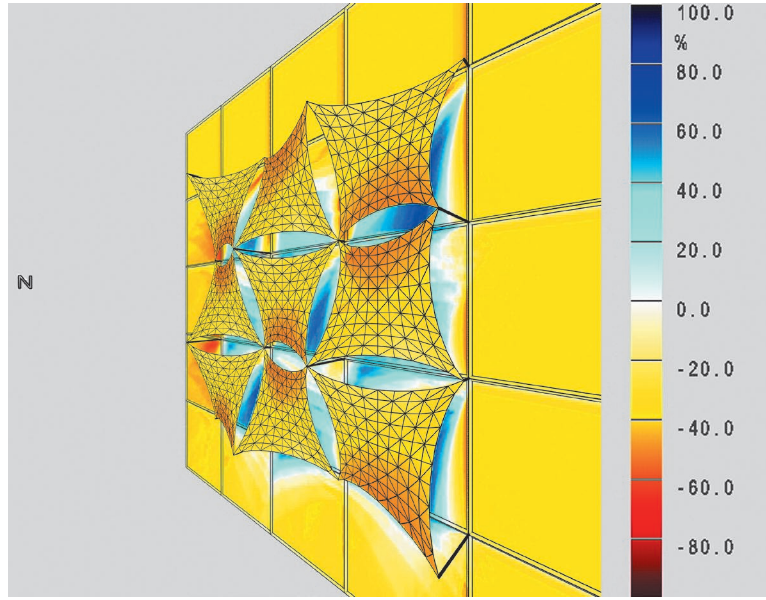
As a general rule in hot climates, it is essential to provide sufficient shade on roofs. However, different concepts and technologies can be used to improve this matter, such as:

1. creating a comfortable outdoor area on the roof as an extension to the building (membrane structures, roof garden, etc.)
2. providing daylight/ventilation for the interior from a shaded roof
3. providing electricity or hot water while shading the roof

In cold climates too, active and passive methods can be used to capture solar radiation. The roof can be sloped to increase the area and the amount of solar radiation, and it can be opened to the sun with a minimum of shading devices.

In climates with both cold and hot conditions, like in Tehran, all mentioned concepts can be applied, but more detailed studies should be made to optimize the concepts so that they work properly in the varied climatic conditions during the year.





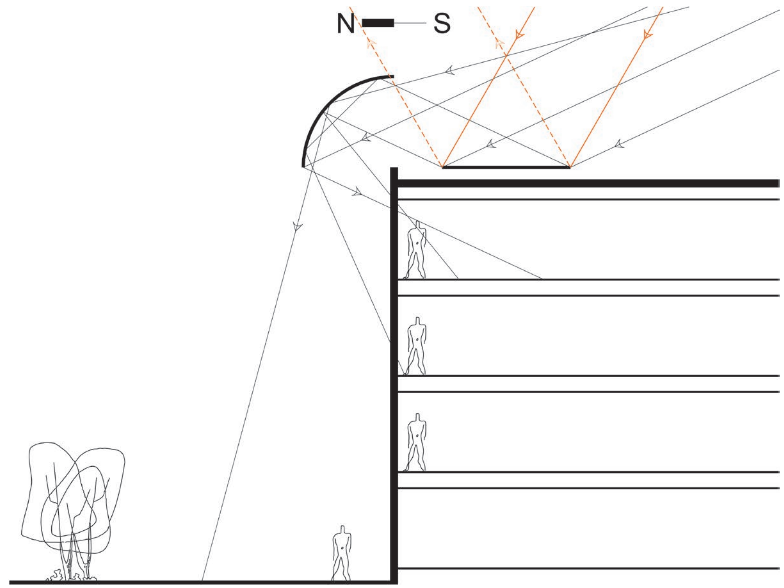


Fig. 171: Interior view of external rotating vertical shading devices during the day (Samimi, 2008) | Fig. 172: The effect of membrane structures in producing shade, daylight and ventilation for building skin (analysis for west direction in Tehran) | Fig. 173: Application of reflective surfaces to direct the sun onto the north side during cold periods (optimized for Tehran), note: the reflectors have to diffuse the light to prevent intensive radiation

The variety of architectural concepts for building skins and their optimization, in regard to the solar-climatic situation of each site and project, is a vast topic which requires greater depth. Nevertheless, the studies presented here in connection with the application of the solar-climatic vision in the architectural design can already help to identify and develop new solutions for current and future problems.

Architectural projects vary in function and scale, ranging from designing or modifying an individual house to the planning of different building typologies in a neighborhood or country. However, there is one similarity in most architectural projects. Similar to the role of a composer or a conductor of an orchestra, the main responsibility of the architect or design team is to organize and structure the combination of layers in the design. Thus, it is the planner's role to create a design concept that meets the client's requirements for a specific site in accordance with the framework of regulations, building codes and guidelines defined by city and country administrations.

The architect's decisions determine people's behavior and affect their health, comfort and safety over a long period of time. In addition to understanding the location and its properties, it is therefore always necessary to consider the current and future users, as well as their significant effects and varied needs over time, throughout the design process.

From the initial phase onwards, architectural variations can be developed in many directions and dimensions. During the design process and in the first sketches, architectural form can take on different states. The architect is the one who can transform the building program into a continuous flow and shape it into a responsible form.

The central role of the building skin in creating and maintaining a good relation between indoors and outdoors was described in the previous parts. In this section, the effects are analyzed in greater detail to show the role of the architectural design in providing internal comfort and reducing the energy demand in connection with the sun and climate. It is necessary, in this context, to study the impact of solar energy on the design, as well as the positive and negative effects of sun in each climate. This process is essential because the form and the orientation of the architectural concept can be changed or modified to maximize the vast benefits of the sun and control the negative effects, especially in hot periods. As

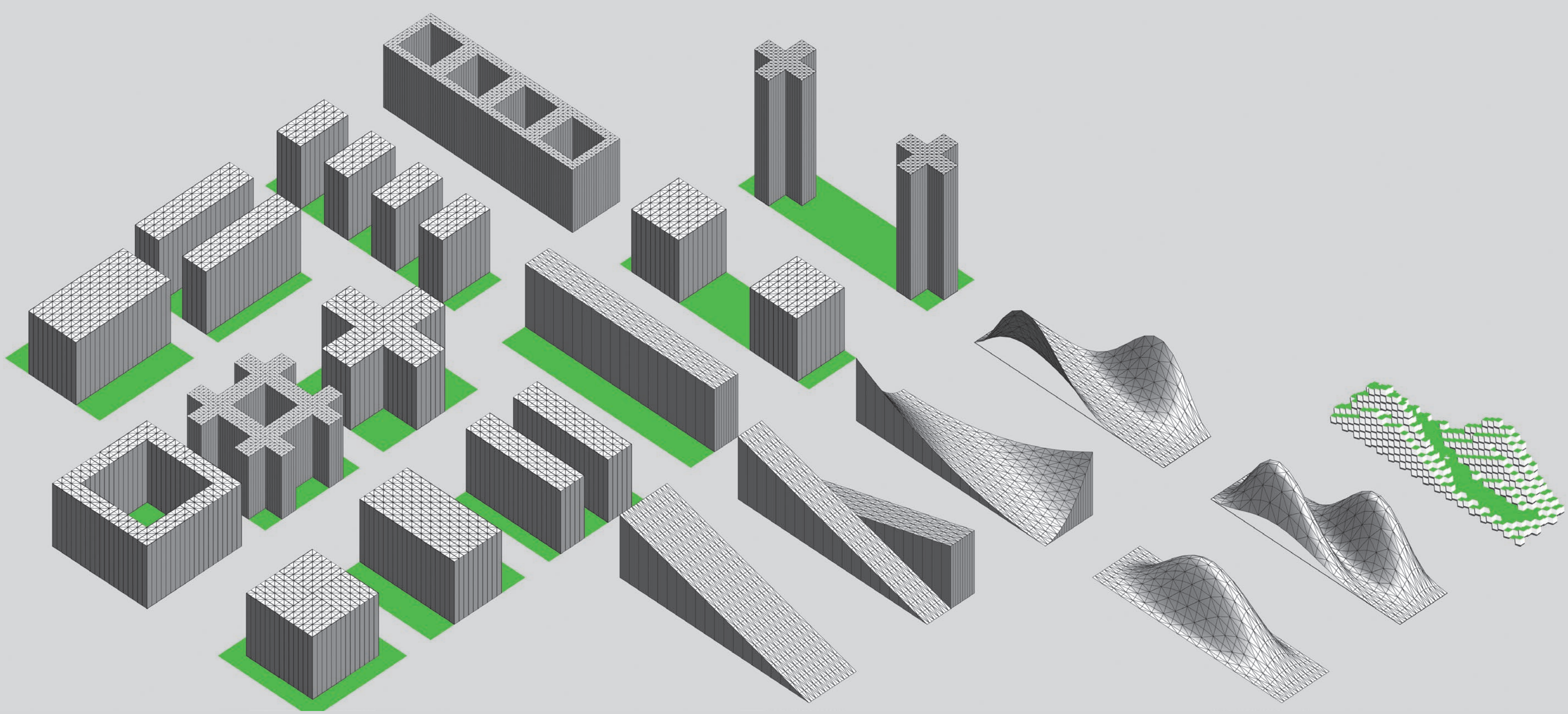


Fig. 174: Basic design studies on the relation between form and plot

was discussed before, the outside effects of the building's orientation and form should be studied in an integrated design process. Consequently, the solar-climatic interactions in the built and/or natural environment are to be analyzed in the proceeding section (section III 4).

Furthermore, a building's geometry and concept has a direct and indirect impact on the whole building system (e.g. structural system, electrical system, lighting and daylighting, HVAC system, access/partitioning system, etc.). To achieve an integrated design, it is necessary to study all the layers, as well as the context, and develop these in a coordinated way

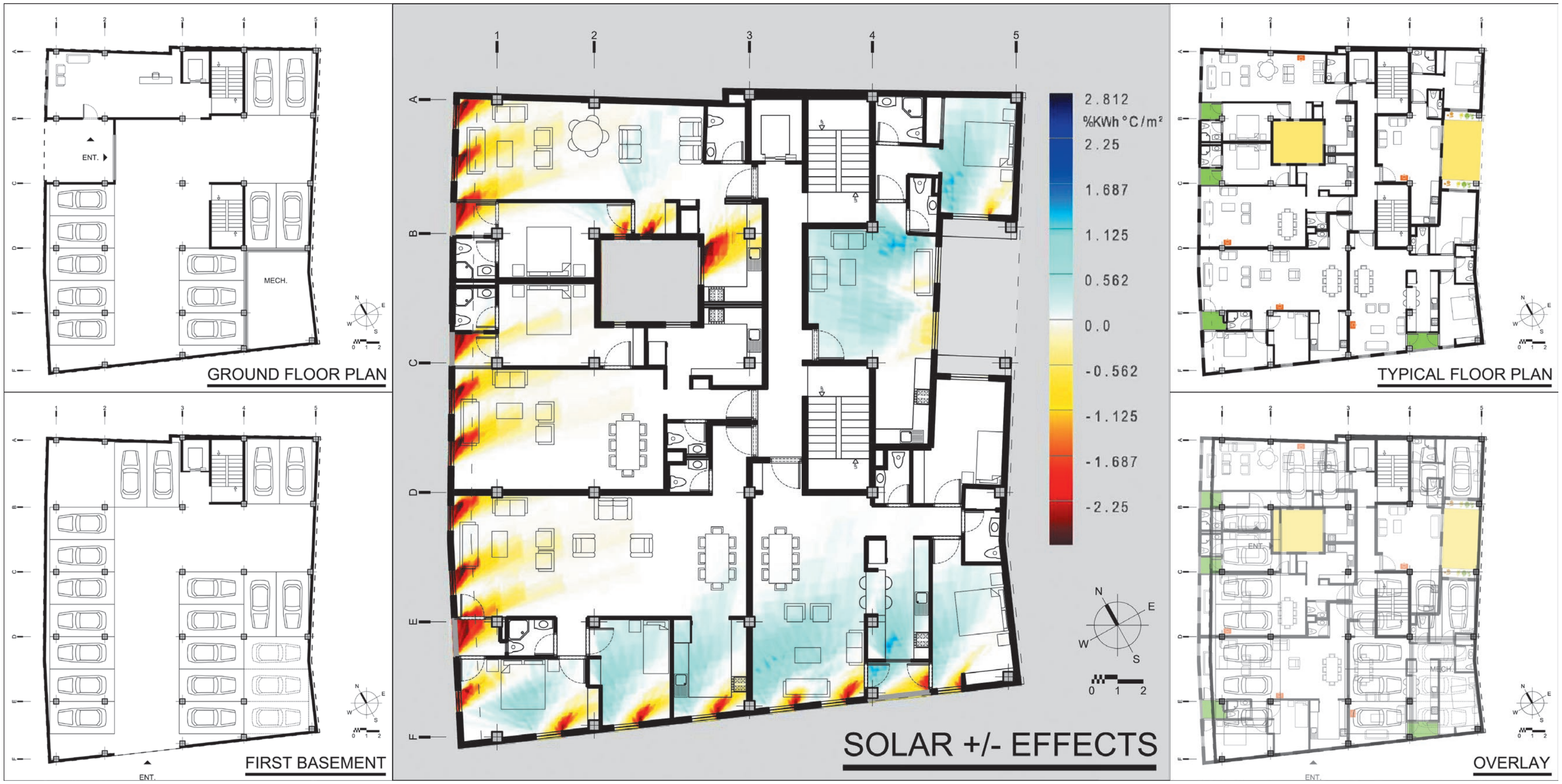


Fig. 175: Layers and overlay plans in a condominium in Tehran, design team: Mojtaba Samimi, Mohammad Yousef Nili and Razieh Tavallaei

throughout the design and optimization process.

The example presented in Figure 175 illustrates some of these layers, as well as their overlay, highlighting the complexities in the design process for an ordinary 5-storey residential building in Tehran. As the outline boundary line of these buildings was defined according to urban regulations, the major architectural challenge was to determine a system that would respond to different layers, namely space division, access, structure, daylight and ventilation, in an optimum way. In addition to the internal and external visual aspects of a building, a passive and active solar-climatic approach to the location of skylights, as well as architectural features in different façades, play a remarkable role in reducing the energy demands and negative impacts, while improving the internal and external qualities. In consideration of the great number and effects of ordinary buildings, solar-climatic studies (e.g. SOLARCHVISION analysis) can help to discover where and how to improve each situation, whether during the design process of a new project or the modification of an existing one.

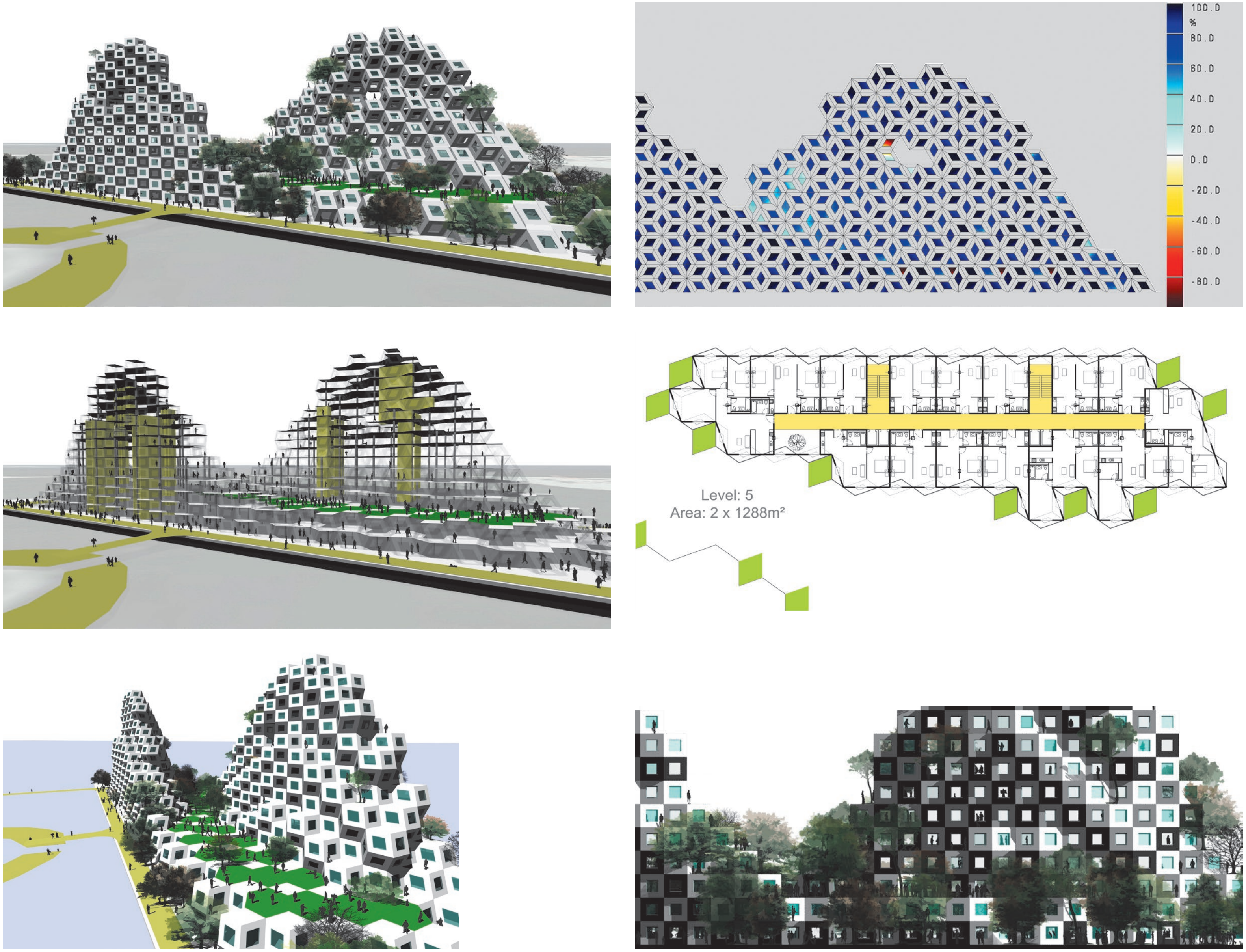


Fig. 176: RE: THINK HOUSING Competition, Vancouver, 2012, Design team: Mohammad Mehdi Ghiyaei, Mojtaba Samimi and Navid Fereidooni

These layers, as well as the level of complexity of new large scale projects, in particular, are the center of avant-garde architects' attention. Due to the limitations of time and budget in the design process, for instance in a competition, different alternatives for building mass must be analyzed by designers, as well as the board of judges, to identify and choose the right architectural concept with the best solar-climatic performance for all internal units as well as public space. The images and the analysis provided in Figure 176 illustrate that new generation forms are responsible for a variety of layers (e.g. structural, spatial, visual, etc.).

Meanwhile, the problem in architectural design today is not about building complex forms inside computers and experimenting with them on large scales outside, but about developing the right architectural form with regard to a variety of parameters and in particular the sun and its varied effects in different climates.

The solar-climatic basic analysis for passive and active strategies provided by SOLARCHVISION can help architects in any city to face local and global challenges. The graphs contain general information and abstract solutions to begin an architectural design in relation to local conditions. As we will see in this section, in addition to applying these basic studies, the SOLARCHVISION spatial analysis and other energy simulation tools (e.g. DesignBuilder) can also be used for more complex and detailed situations.

Two basic diagrams for Tehran are presented in Figure 177 to show the positive and negative solar effects at each hour during different months, as well as the annual score of each direction, calculated by the SOLARCHVSION tool. The annual score of each building surface orientation and inclination can be read from the graphs and applied in the architectural design to optimize the form. It is easy to determine the potentials and critical points as these are illustrated as blue and red areas. According to the diagram, the most inadequate surface for openings in Tehran is a surface with a +50° inclination and an orientation of -150° (north-west). That is simply because it receives the greatest amount of direct solar radiation during hot periods, whereas it receives little direct and indirect radiation in cold periods. The positive and negative amounts for this building surface add up to +5.689 and -17.367 kWh°C/m² on average for 365 days. In comparison to this solution, the situation of a similar inclined surface oriented west is better as it receives more direct radiation on cold days in Tehran. Out of all vertical surfaces (e.g. regular windows and walls), presented by the bold circle, surfaces facing west (e.g. -105°) are the least suitable, but they can be improved by using horizontal shading devices. There is a large area of blue between east and south-west, which means that these vertical surface orientations can be opened to the sun. The performance of these orientations can be improved significantly by adding a narrow horizontal shading device. No matter which orientation is chosen, the effect of shading devices can be compared to situations without shading devices by using the circle which corresponds to the inclination of the Horizontal Shading Angle (e.g. HAS: -20°). On the other hand, by using deeper shading devices for orientations from east to south-west in Tehran, the amount of heat gain in winter is reduced. That is why these cases have a lower solar-climatic performance score in comparison to the -20° inclination in the diagram. The positive and negative amounts for the most extreme point in the diagram add up to +11.440 and

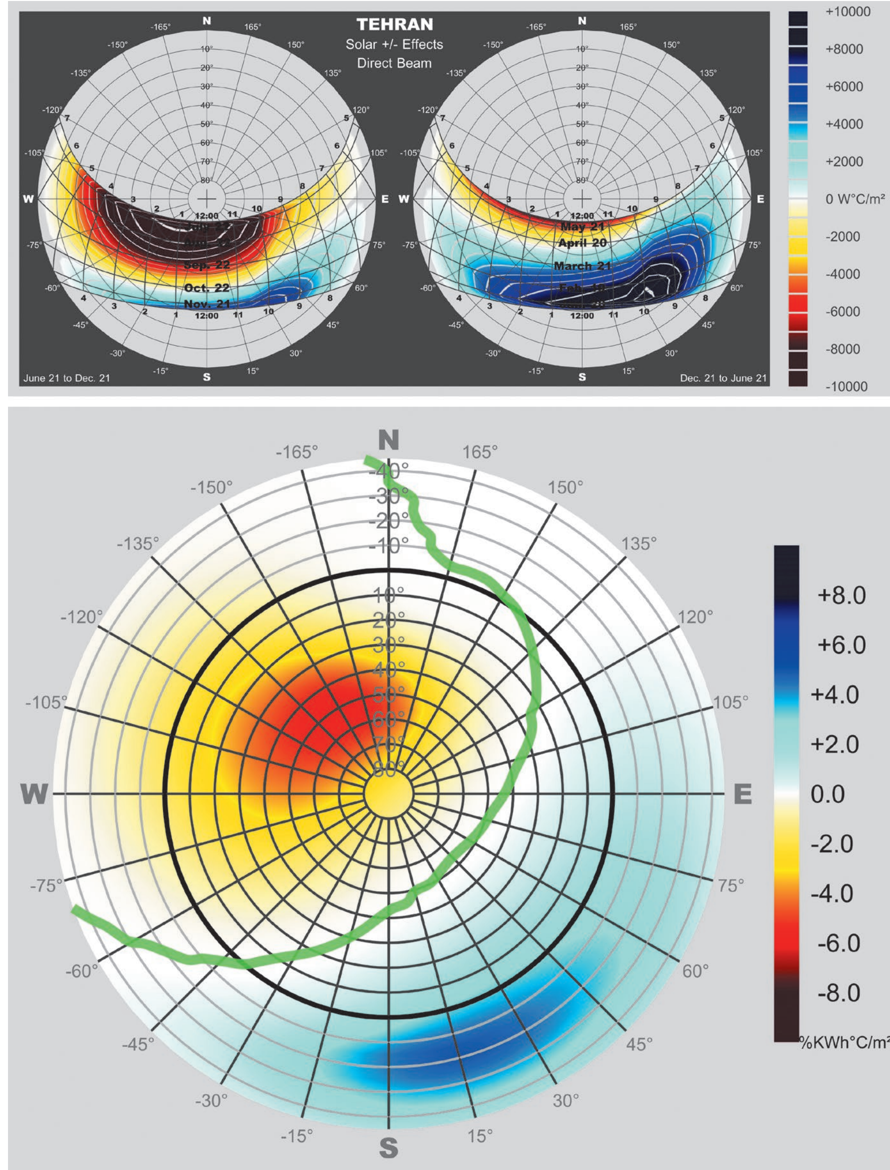


Fig. 177: Orientations and solar effects, top: general positive and negative effects of the sun in Tehran (left: from 21 June to 21 December, right: from 21 December to 21 June), bottom: analysis of annual solar +/- effects of direct and diffuse radiation on different surfaces and inclinations in Tehran

-2.986 KWh°C/m² on average for 365 days in Tehran. These values apply to an almost south-facing façade with a slight overhang (orientation: 15°, inclination: -20°).

The green line and the wide white area surrounding it separate the surfaces which require a shading device (red and yellow) from the other surfaces which are positive in terms of their solar-climatic performance throughout the year. The use of adjustable shading/reflecting devices is recommended for the white middle zone as it can improve the performance of the building in regard to the variable effects of the sun on these surfaces throughout the year.

The values presented in Table 3 are taken from the annual passive analysis of orientations and inclinations for Tehran. As is described in section “Different surfaces facing the sun”, these values result from the multiplication of ratio layers and the total of annual positive and negative effects of solar radiation on each surface. A high positive value presents a high potential of the surface to be opened to the sun, because it receives a great amount of solar energy during the heating period, at the same time as being protected from unfavorable solar radiation during the cooling period thanks to its particular orientation and inclination in relation to the sun path and the local patterns of temperature change. A high negative value presents a critical situation as the surface receives a large amount of solar energy during the cooling period.

To calculate similar scores for a cubic building, it is necessary to establish the advantages and disadvantages of solar energy (in relation to energy-efficiency) for each surface separately and put them into the described functions. A simple sum of the results for each orientation is also useful in an approximate manner to compare different alternatives (Figure 180). The following studies illustrate the application of this method for assessing different architectural alternatives based on the estimated solar-climatic performance or by using the total positive and negative points. In regard to this study, which is performed for Tehran, slightly better interior conditions can be obtained by the cardinal directions than those with a 45° rotation. On the other hand, the application of optimized shading devices is a more important aspect than the building orientation. This means that optimized shading/reflecting devices can improve the solar-climatic performance of buildings significantly. As an example, a 45°-rotated design with optimized shading devices performs better than the same building with cardinal directions but without any shading devices.

Orientation	**With inclination or with horizontal shading device**
S = +2.282	S~ = S.@-20° = +4.340
SE = +2.95	SE~ = S.E.@-15° = +3.680
E = +1.015	E~ = E.@-10° = +1.167
NE = +0.008	
N = -0.011	
NW = -1.464	NW~ = N.W.@-45° = -0.059
W = -1.565	W~ = W.@-45° = -0.062
SW = -0.021	SW~ = S.W.@-35° = +0.284
Roof = -1.831	Maximum @ Dir. : +15°, Inc. : -20° = +4.954
	Minimum @ Dir : -150°, Inc. : +50° = -5.916

Tab. 3: Overview of SOLARCHVISION passive scores in correspondence to the annual positive and negative solar effects on different surfaces and inclinations in Tehran

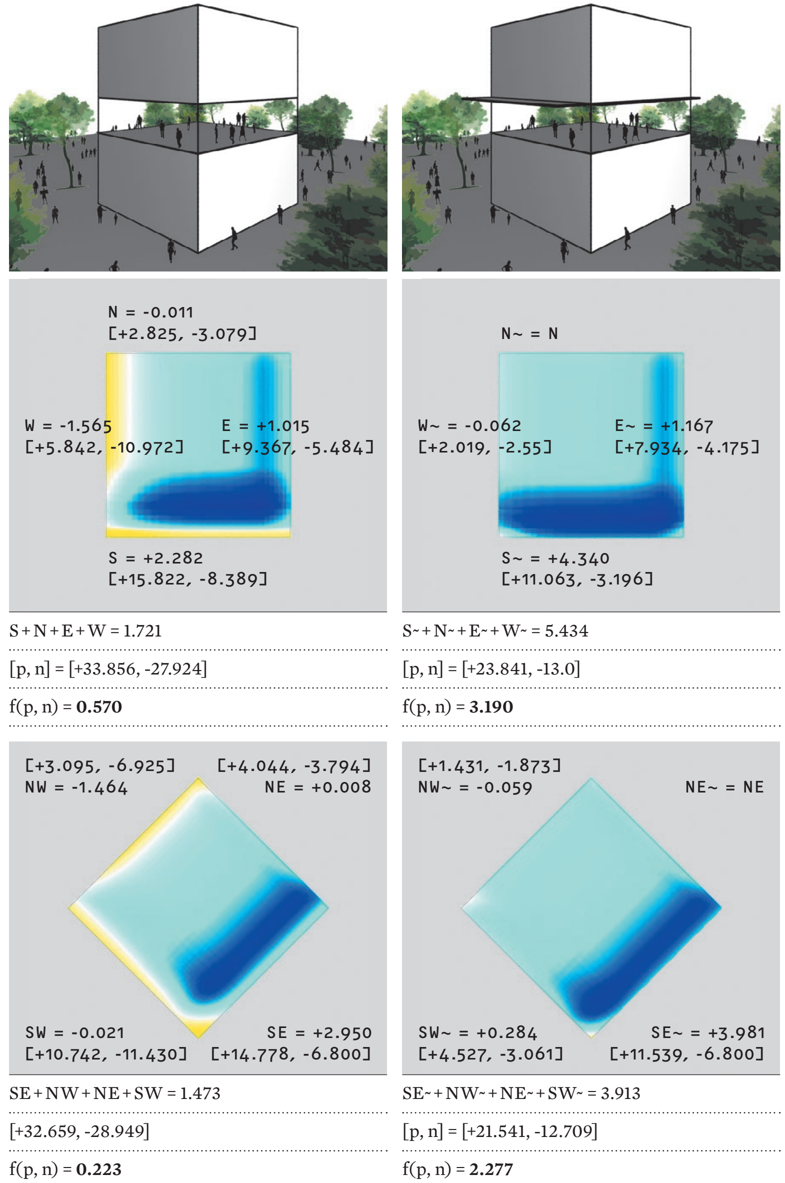
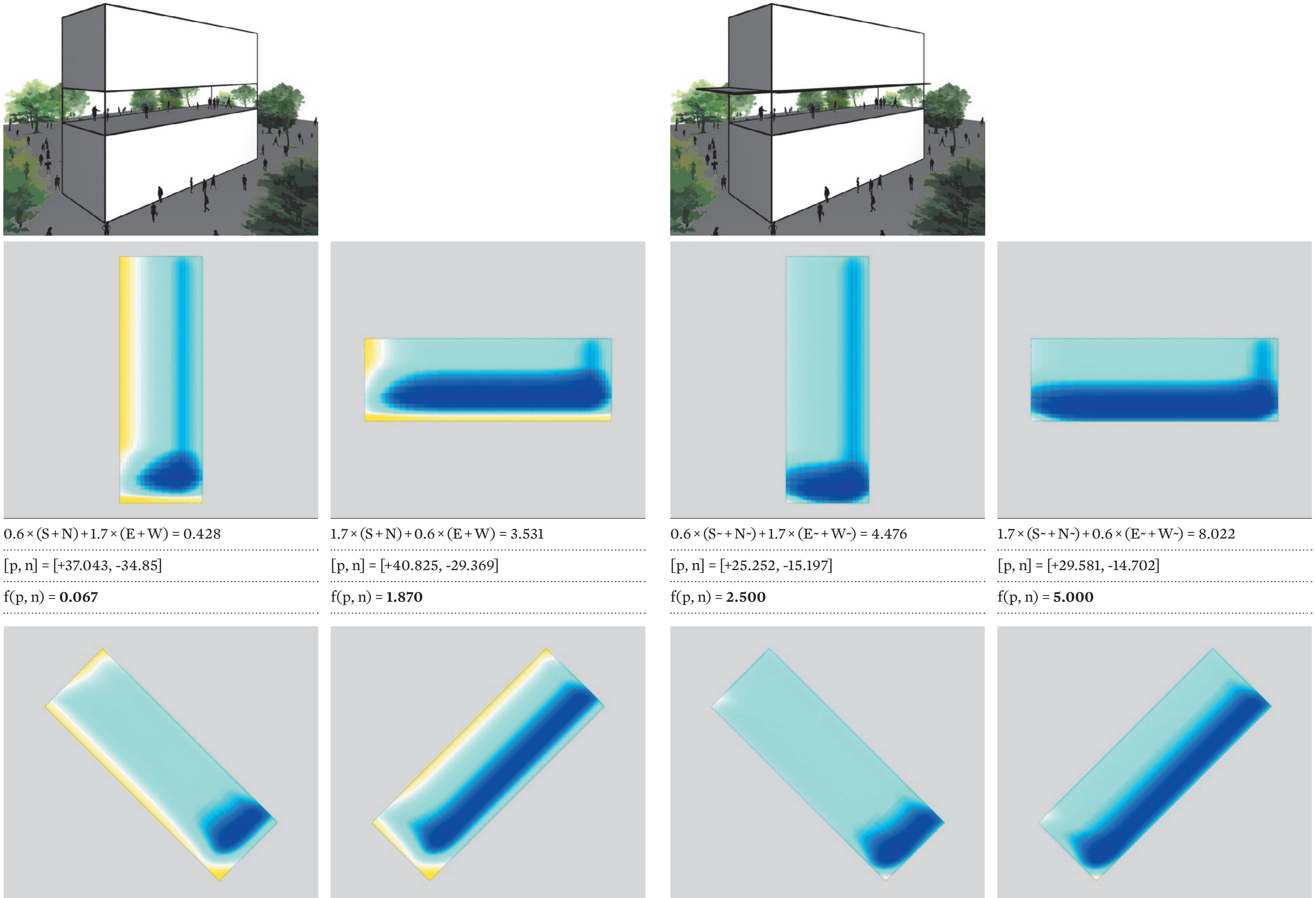


Fig. 178: SOLARCHVISION spatial and basic analysis of variations with different orientations and with or without overhangs for a 12x12x3m interior space in Tehran



0.6 × (S + N) + 1.7 × (E + W) = 0.428	1.7 × (S + N) + 0.6 × (E + W) = 3.531	0.6 × (S~ + N~) + 1.7 × (E~ + W~) = 4.476	1.7 × (S~ + N~) + 0.6 × (E~ + W~) = 8.022
[p, n] = [+37.043, -34.85]	[p, n] = [+40.825, -29.369]	[p, n] = [+25.252, -15.197]	[p, n] = [+29.581, -14.702]
f(p, n) = **0.067**	f(p, n) = **1.870**	f(p, n) = **2.500**	f(p, n) = **5.000**
0.6 × (SE + NW) + 1.7x(NE + SW) = 0.870	1.7 × (SE + NW) + 0.6 × (NE + SW) = 2.518	0.6 × (SE~ + NW~) + 1.7 × (NE~ + SW~) = 2.669	1.7 × (SE~ + NW~) + 0.6 × (NE~ + SW~) = 6.331
[p, n] = [+35.860, -34.115]	[p, n] = [+39.255, -32.466]	[p, n] = [+22.352, -15.165]	[p, n] = [+27.191, -14.064]
f(p, n) = **0.043**	f(p, n) = **0.643**	f(p, n) = **1.377**	f(p, n) = **4.177**

Fig. 179: SOLARCHVISION spatial and basic analysis of variations with different orientations and with or without overhangs for a 28x8x3m interior space in Tehran

The positive or negative potentials of each orientation can also be applied to the length of each façade (or in relation to the area of openings in that façade) to assess variations with different elongations.

$$p = Total\_advantages = \sum_{i=1}^{n} a_i \times p_i$$

$$n = Total\_disadvantages = \sum_{i=1}^{n} a_i \times n_i$$

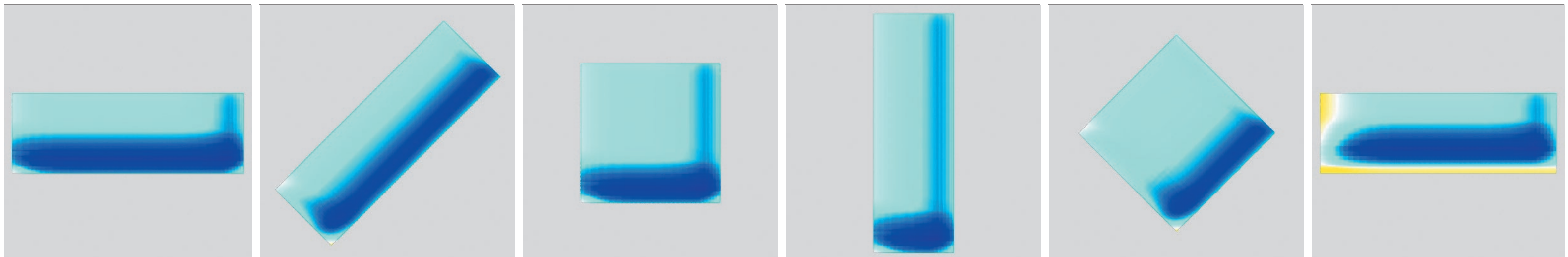
$$f(p, n) = \frac{p-|n|}{p+|n|} \times |p-|n||$$

As is illustrated in Figure 179, this study, which is again performed for Tehran, determines that a simple south-oriented building can provide much better interior conditions than an east/west-oriented one. However, if the façades of an east/west-oriented building are improved with shading devices, balconies, etc., the conditions are similar or better than a south-oriented design without shading devices.

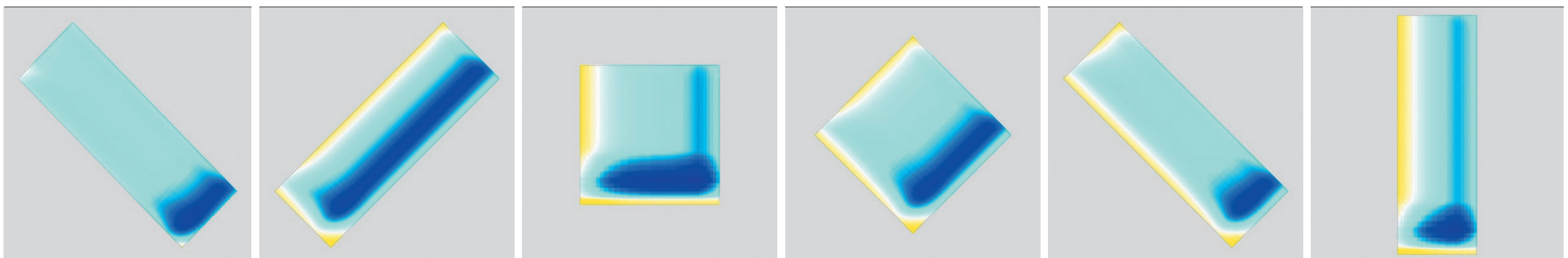
As is mentioned before, the annual positive effect of the sun has to be studied for each orientation to determine the more detailed differences between these situations. A comparison of the positive and negative amounts of direct and diffuse radiation on different vertical surfaces (e.g. regular windows) is presented for an annual cycle in Tehran in Table 4. It demonstrates that a significant reduction of undesirable radiation can be achieved in the cooling period and the amount of desirable heat gain differs only slightly in the heating period by using overhang systems that have been improved in terms of their orientation based on local climatic statics. The calculation method to determine the SOLARCHVISION passive scores according to the varied negative and positive amounts is explained by using the information in this table.

The analysis of different variations for the selection of the best solution is a major task in the decision making and design process. Each variation needs to be improved carefully to achieve the most enhanced result. The SOLARCHVISION studies presented in this section for different architectural concepts are an analytical method to assess a wide variety of architectural solutions with the aim of creating a healthy, comfortable, energy-efficient interior environment. Nevertheless, a perfect result can only be achieved if all aspects are optimized in a holistic way. This means in consideration of the effects these improvements have on other architectural aspects and by taking the whole design, construction and operation process into account.

Figures 181–182 show the application of the SOLARCHVISION spatial analysis to identify the effects of shading devices in each orientation according to the solar-climatic performance of the building skin. With regard to this analysis, which is performed for Tehran, an increase in the intensity of the blue area on the south façade achieved through the appli-



	S+N with overhang	SE+NW with overhang	S+N+E+W with overhang	E+W with overhang	SE+NW+NE+SW with overhang	S+N without overhang
p+n	8.022	6.331	5.434	4.476	3.913	3.913
f(p, n)	**5.000**	**4.177**	**3.190**	**2.500**	**2.277**	**2.277**



	NE+SW with overhang	SE+NW without overhang	S+N+E+W without overhang	SE+NW+NE+SW without overhang	NE+SW without overhang	E+W without overhang
p+n	2.669	2.518	1.721	1.473	0.870	0.428
f(p, n)	**1.377**	**0.643**	**0.570**	**0.223**	**0.067**	**0.043**

Fig. 180: Architectural variations sorted according to the estimated solar-climatic passive performance of the interior/skin in terms of proportions, shading devices and orientations in Tehran

cation of a designated device is considered to be most effective. It is worth noting that the constructional element in this façade does not create shade in winter even though it is generally referred to as a shading device.

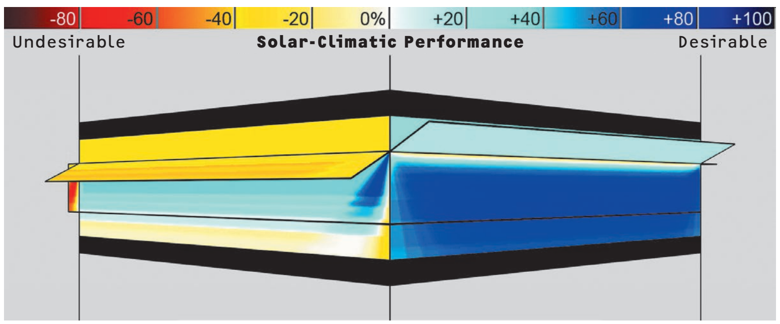
According to the analysis in Figure 181, shading devices are also considered helpful on west façades; however, not as effective as those on a south façade. The solution most appropriate for the south façade is not as effective in the west façade as it does not create sufficient shade in summer. There are better alternatives, as presented in figures 163 and 168, to improve the situation of a west façade. Despite this observation, this solution is being used for further analysis, because it is simpler and generally considered a more practical way of blocking out the sun. Concerning the east orientation, the yellow area below the horizontal shading device illustrates the fact that shade is created in winter. Again upward-tilted louvers can provide a better situation for both summer and winter conditions; however, it is also advisable to raise them to improve the window situation. And finally for the north direction: vertical shading devices have been analyzed which show a slight improvement for this orientation.

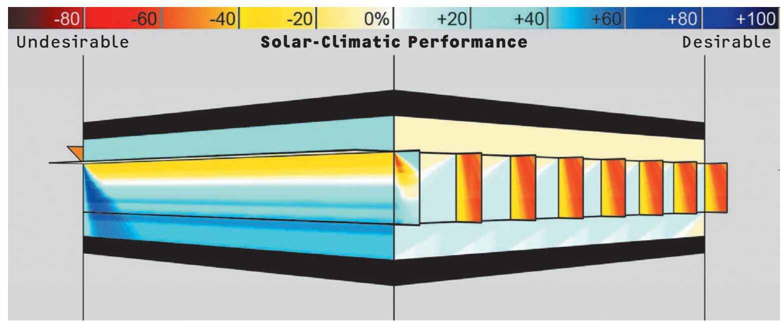
Further experiments, as well as studies using another simulation tool, demonstrate how much energy can be saved by applying a solar-climatic vision in the architectural design.

In the following analysis, which is carried out using the DesignBuilder simulation tool, three different alternatives with different elongations in the cardinal directions have been studied. The plots of energy consumption are presented for heating and cooling in a typical year. Two cases have been simulated for each of these instances: one without shading devices and the other one with shading devices.

The dimensions of the buildings as well as the shading devices are presented in Figure 183. The proposed shading devices for each orientation are exactly the same as those which were studied by the SOLARCHVISION program above.

Negative kWh°C/m²/day	**Positive** kWh°C/m²/day	**Ratio.Total**	**Orientation** %kWh°C/m²/day	**With inclination** %kWh°C/m²/day	**Ratio.Total**	**Positive** kWh°C/m²/day	**Negative** kWh°C/m²/day
−8.389	+15.822	+0.307 × +7.433	S = +2.282	S~ = S.@−20° = +4.340	+0.552 × +7.867	+11.063	−3.196
−6.800	+14.778	+0.370 × +7.978	SE = +2.950	SE~ = S.E.@−15°= +3.680	+0.487 × +7.558	+11.539	−3.981
−5.484	+9.367	+0.261 × +3.883	E = +1.015	E~ = E.@−10° = +1.167	+0.310 × +3.759	+7.934	−4.175
−3.794	+4.044	+0.032 × +0.250	NE = +0.008				
−3.079	+2.825	−0.043 × −0.254	N = −0.011				
−6.925	+3.095	−0.382 × −3.830	NW = −1.464	NW~ = N.W.@−45° = −0.059	−0.134 × −0.442	+1.431	−1.873
−10.972	+5.842	−0.305 × −5.130	W = −1.565	W~ = W.@−45° = −0.062	−0.116 × −0.531	+2.019	−2.55
−11.430	+10.742	−0.031 × −0.688	SW = −0.021	SW~ = S.W.@−35° = +0.284	+0.193 × +1.466	+4.527	−3.061
−24.140	+15.610	−0.215 × −8.530	Roof = −1.831				





Tab. 4: Annual solar positive and negative effects of direct and diffuse radiation on different vertical surfaces (e.g. regular windows with or without horizontal shading devices) in Tehran and their corresponding SOLARCHVISION passive scores | Fig. 181–182: Solar-climatic design performance analysis in Tehran's climate for different types of shading devices in respect of their orientation, left: SW view, right: NE view

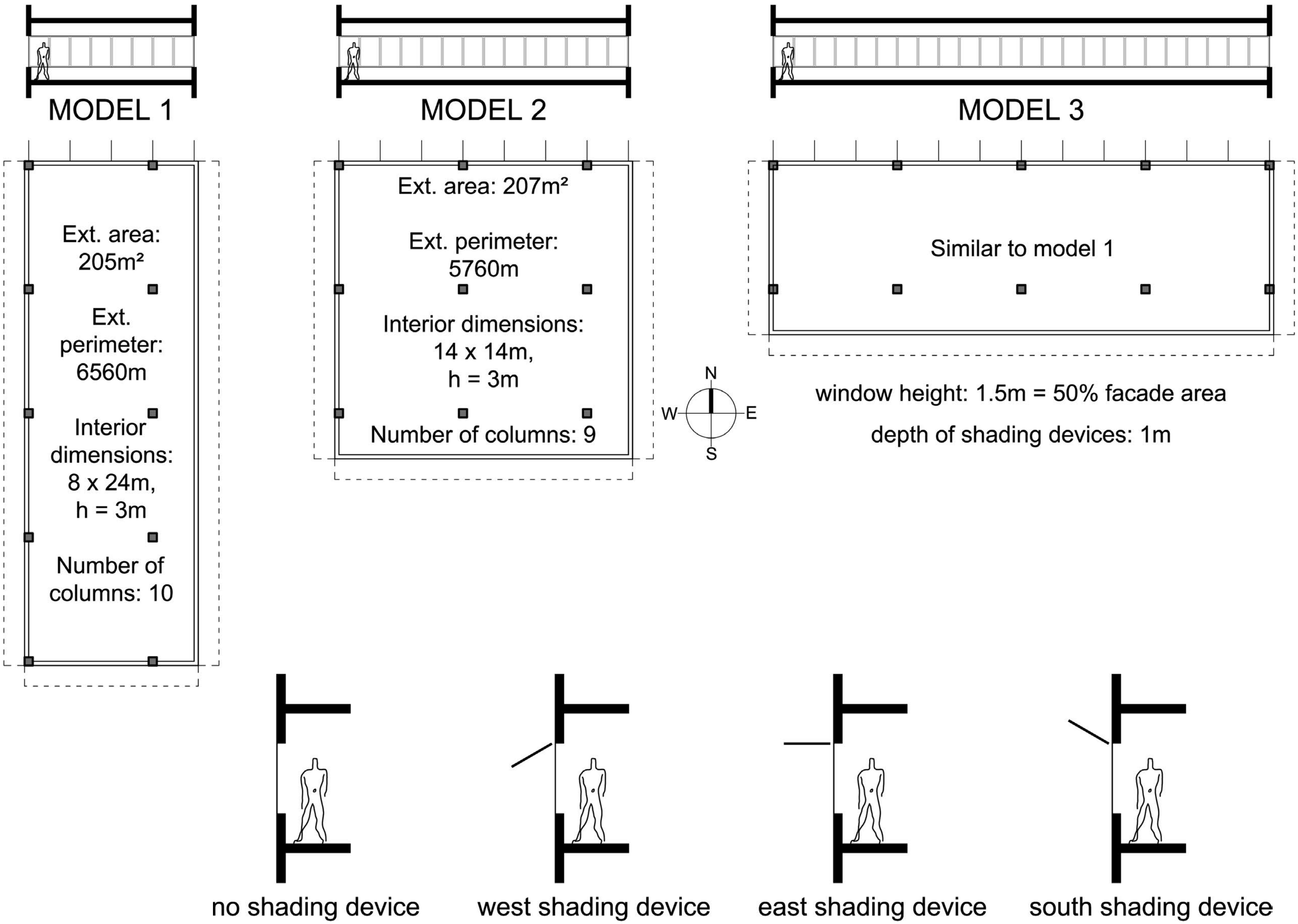


Fig. 183: Comparison of three model buildings for creating about 200m² of interior space with a 6m x 6m structural grid as well as typical façade profiles

The aim of artificial heating and cooling in buildings using appropriate heating, ventilation and air conditioning (HVAC) systems is to balance the heat gains and losses of buildings. Thus, the heating and cooling energy demands of buildings depend directly on the heat gains and losses during the heating and cooling periods. Among all internal and external heat gains of the building, the solar heat gain contributes most; however, its amount depends on factors such as the climate, building form, area of transparent and opaque surfaces, thermal resistance of the building envelope, etc. The total heat gain, including the solar heat gain, increases the internal air temperature. Thus, solar heat gain is an advantage in the heating period and a disadvantage in the cooling period. Consequently, in order to minimize artificial heating and cooling, the solar heat gain must be minimized in summer and maximized in winter. This is where solar-climatic studies should be applied to analyze the pros and cons of solar heat gain in the heating and cooling periods.

As is discussed before, there are several critical parameters which reflect on the solar-climatic performance. The most important energy-related factors are orientation, window ratio in different orientations, elongation, shading devices, etc. The three parameters studied here are building elongation, solar-climatic performance of the apertures and orientation. The mathematical calculations applied by the SOLARCHVISION method for the complex climate of Tehran with cold winters and warm summers are presented in Tables 3 and 4.

Three model buildings, dimensioned according to Figure 183, are analyzed in this section using the DesignBuilder simulation tool to identify the heating and cooling energy demands. The model buildings are simple single-story, single-zone residential buildings. It is assumed that the model building is part of a multi-story building, which has no heat gains and losses through the roof and floor. This assumption helps to minimize the effect of transmission heat gains and losses through these two building elements and means that this control variable can be neglected in the results.

The energy demand is compared to present the effect of orientation, elongation and shading devices in all three model buildings. All building characteristics are identical; only the orientation, shading devices and elongation are varied. The buildings are compared by changing only one variable factor at a time. The physical properties of the thermal envelope, the thermal comfort conditions and the efficiency and fuel of the heating and cooling systems are as follows:

U-value$_{\mathbf{Wall}}$: 0.35 W/m^{2}k, U-value$_{\mathbf{Roof}}$: 0.35 W/m^{2}k,
U-value$_{\mathbf{Window}}$: 1.96 W/m^{2}k, total solar transmittance (SHGC): 0.691, infiltration: 0.7 ac/h
heating setpoint temperature: 21°C, cooling setpoint temperature: 26°C
heating system COP: 0.62, heating fuel: natural gas, cooling system COP: 1.32, cooling fuel: electricity

All these factors are important in influencing the energy demands of the buildings. Furthermore, the factors are dependent on one another, and by changing one of them, the most perfect solution for the others is no longer guaranteed. For example, the perfect window area in each cardinal direction varies depending on the materials of the opaque and transparent elements in the thermal envelope. Consequently, by changing the window area in each direction, the best orientation from an energy efficiency point of view also changes. If the climate parameters, including air temperature, relative humidity, direct and diffuse solar radiation, wind direction and wind speed, were also to be considered architectural and/or constructional characteristics, there would be an even greater variety of parameters, which are dependent on one another. The energy behavior of buildings is, therefore, very complex and it is difficult to make accurate statements on energy efficiency for all buildings.

How solar radiation affects the energy behavior of a building depends on a variety of factors, and, to make accurate decisions, each building must therefore be studied individually. Energy improvement decisions must be made throughout all stages of the design. In terms of improving solar radiation, however, it is possible to make some general statements for all buildings at an early stage of the design. These statements must be based on quantitative analyses.

The energy simulation study illustrates that the improvements achieved by a solar-climatic vision in the design of the building skin is in accordance with the SOLARCHVISION results. It also demonstrates the significant effect the architectural design, as well the improvement of the building skin, has on the energy demands for heating and cooling.

Analysis of the Effect of an Optimized Building Envelope in Tehran in Terms of Energy Demand

In order to study the effect of shading devices on the energy demand, the model buildings are simulated and compared with and without optimized shading devices. The shading devices influence the amount of solar radiation incident reaching the windows and penetrating the building, and thus influencing the amount of solar heat gain.

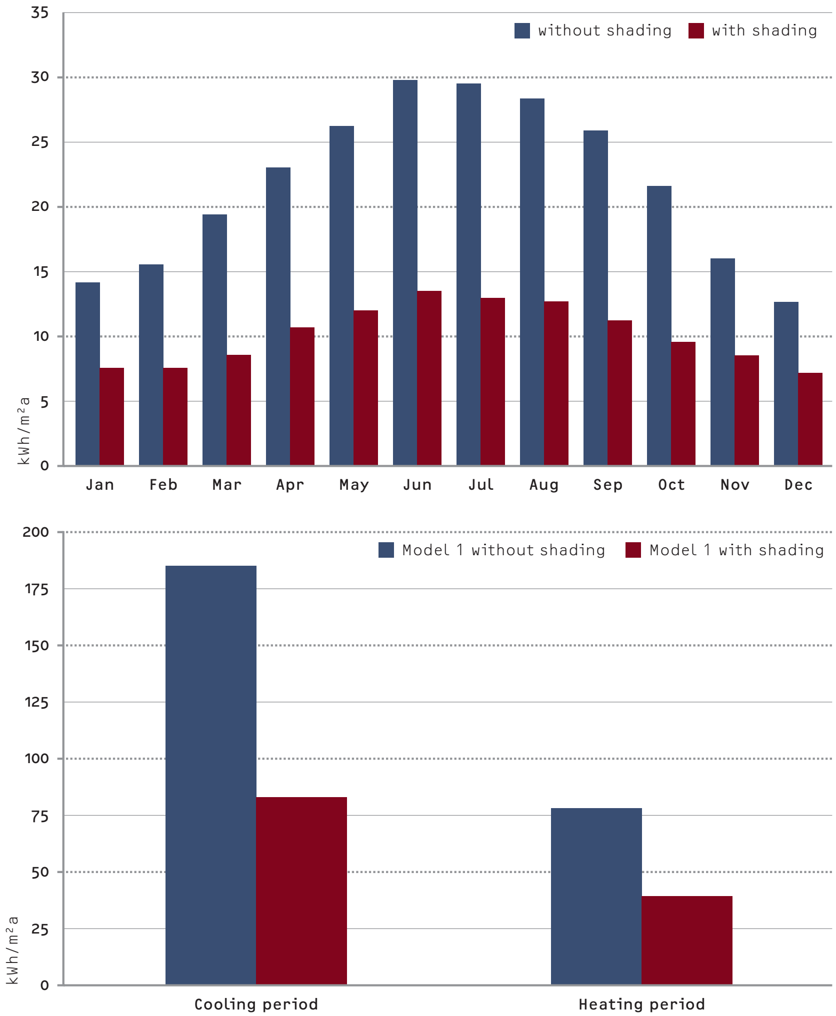


Fig. 184–185: Monthly solar heat gains (above) and solar heat gains in the heating and cooling periods (below) in model building 1 with and without optimized shading devices

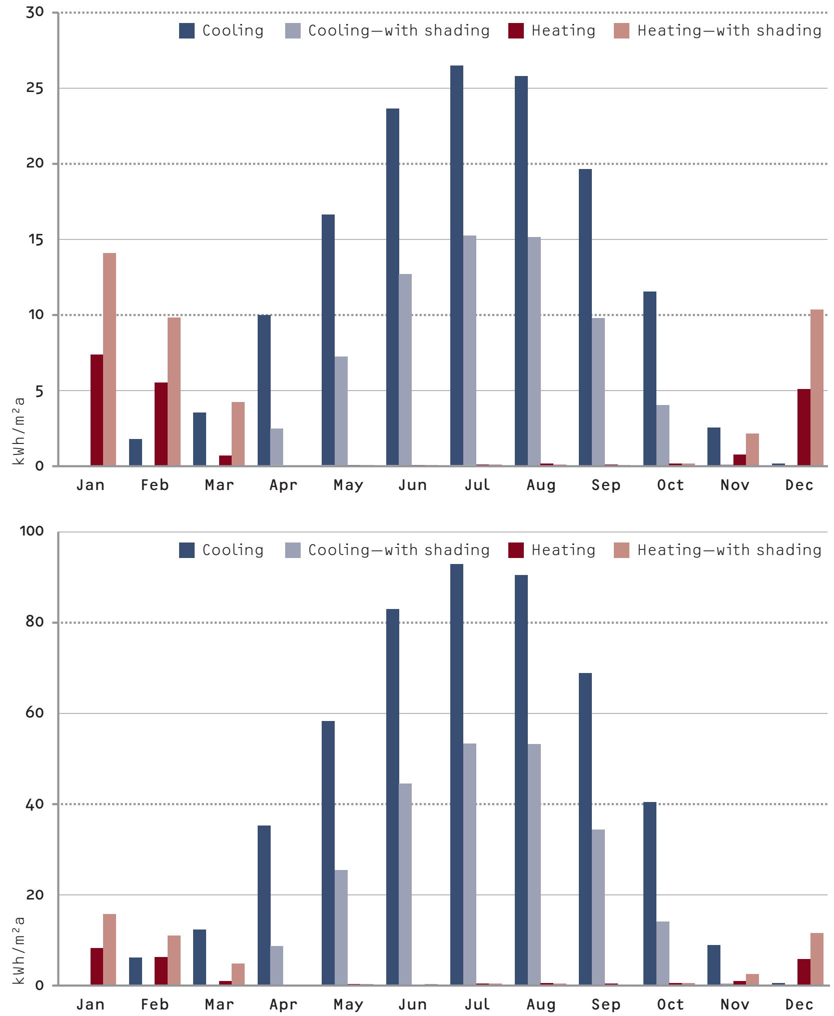
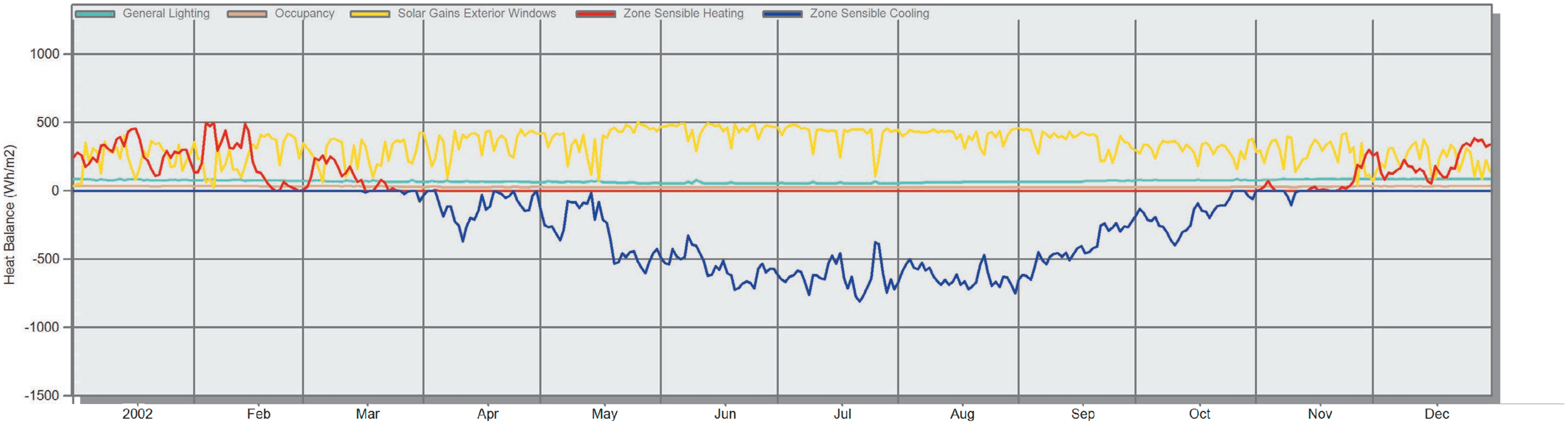


Fig. 186–187: Monthly heating and cooling energy demand (above) and monthly primary energy demand (below) in model building 1 with and without optimized shading devices

Model Building 1

Figure 184 compares the monthly solar heat gains of model building 1 with and without shading devices. According to this graph, the solar heat gain of the building with optimized shading devices is reduced effectively in the cooling period, which leads to a reduction of cooling energy demand. The solar heat gain is also reduced slightly in the heating period, which marginally increases the heating energy demand. According to figure 185, the total reduction of solar heat gain in the cooling period is much higher than the reduction of solar heat gain in the heating period.

Figure 186 compares the monthly heating and cooling energy demands of model 1 with and without shading devices. It shows that the cooling energy demand of the building with a solar-climatic optimized building skin is much lower than that of an ordinary building without shading devices or one with inadequate shading devices. The heating en-



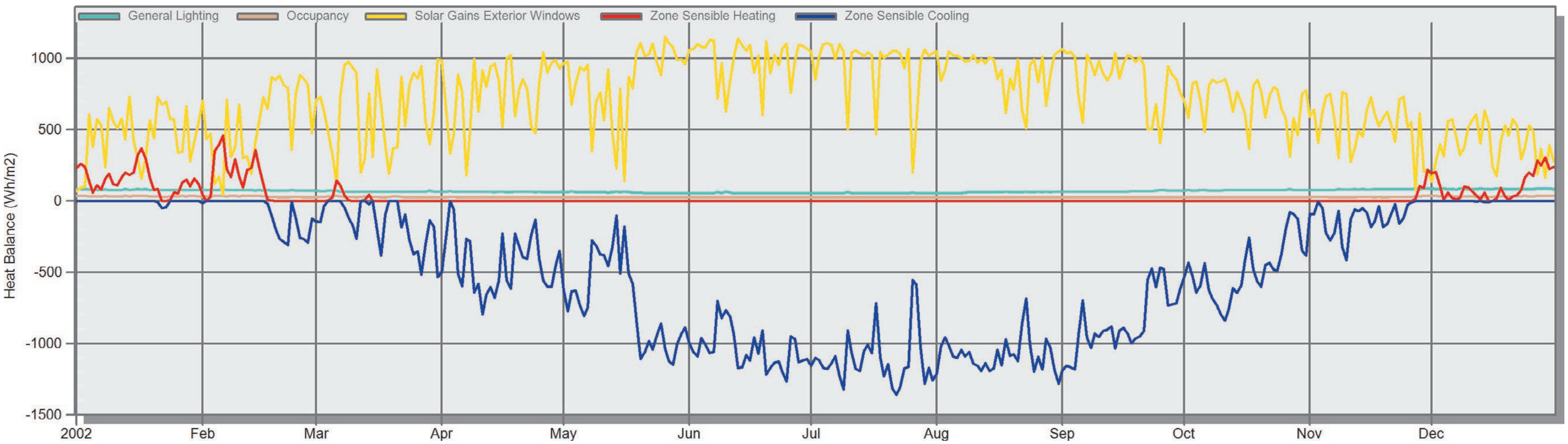


Fig. 188–189: Daily internal heat gains (solar heat gain and heating and cooling energy demand) of model building 1 with and without optimized shading devices (yellow: solar gains from windows, red: sensible heating, blue: sensible cooling, cyan: general lighting, pink: occupancy)

ergy demand is increased by applying shading devices, but the total energy demand is decreased significantly by using optimized shading devices at windows.

The use of optimized shading devices leads to savings of 50.14% for the sum of the heating and cooling energy demand and savings of 86.11% for the primary energy demand for heating and cooling. The savings in the primary energy demand are higher than those of the total heating and cooling energy because the application of shading devices primarily reduces the cooling energy demand, which consumes electricity with a higher primary energy factor than natural gas.

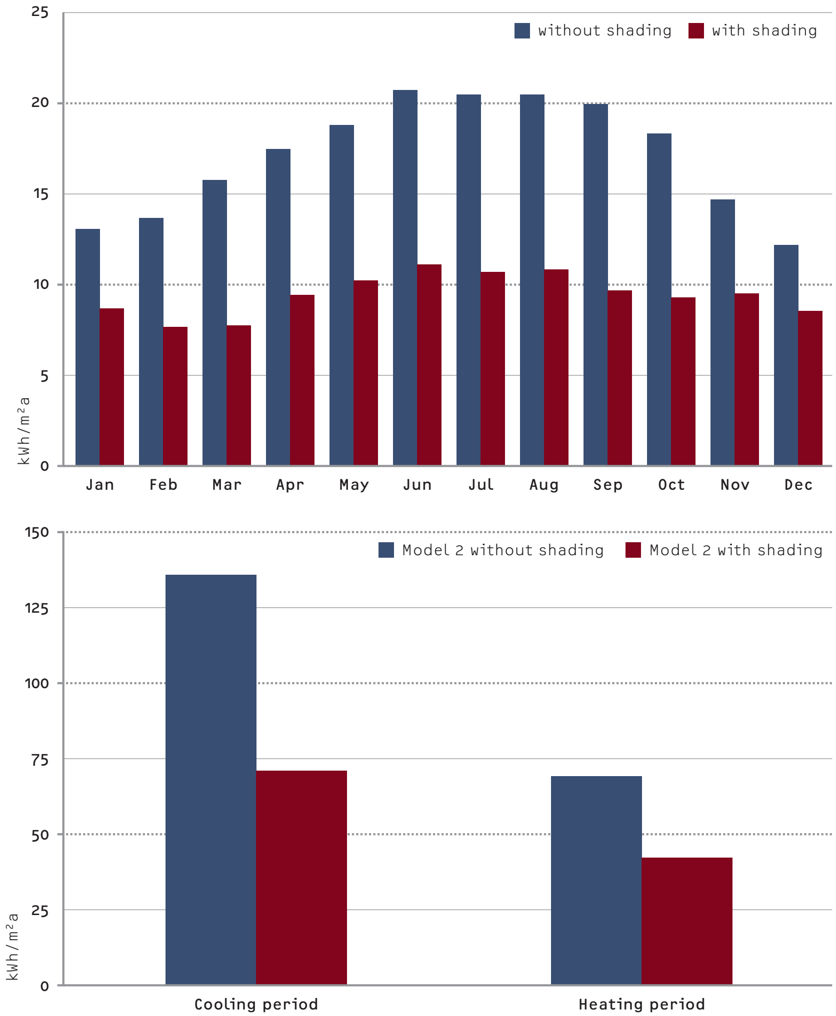


Fig. 190–191: Monthly solar heat gains (above) and solar heat gains in the heating and cooling periods (below) in model building 2 with and without optimized shading devices

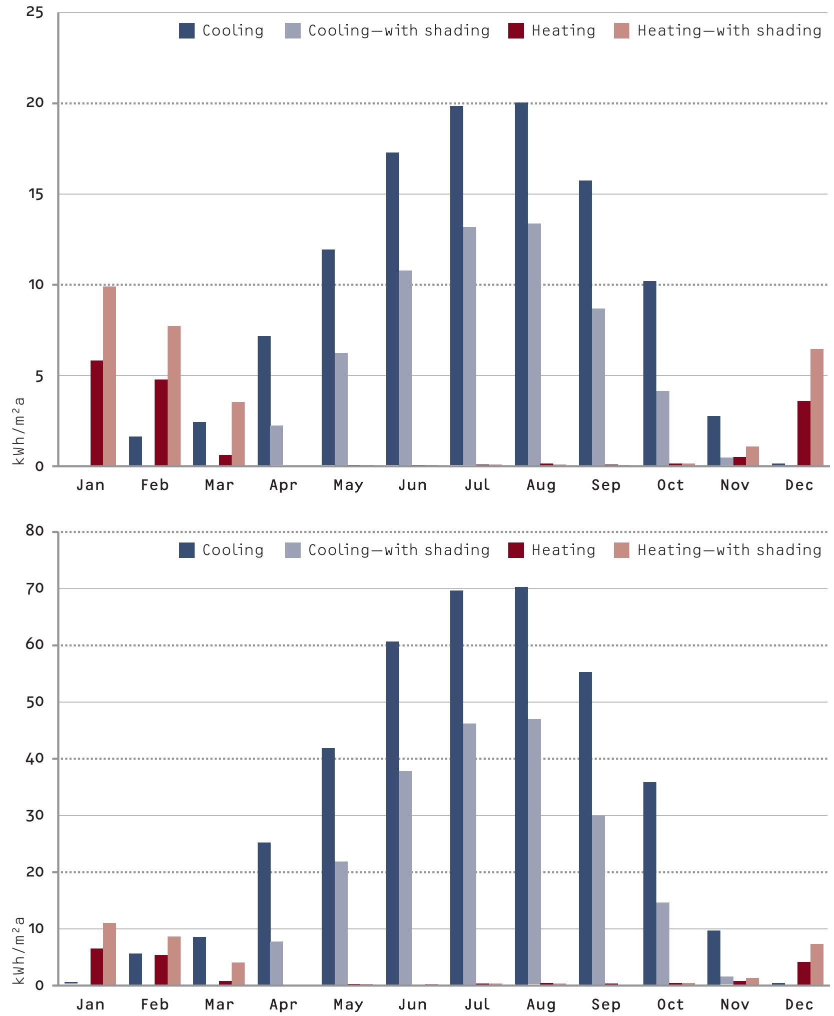


Fig. 192–193: Monthly heating and cooling (above) and monthly primary energy demand (below) in model building 2 with and without optimized shading devices

Model Building 2

Figure 190 presents the monthly solar heat gains of model building 2 with and without shading devices. The solar heat gains of building 2 are reduced effectively in the cooling period; thus, decreasing the cooling energy demand. However, the solar heat gains are also decreased slightly in winter, which marginally increases the heating energy demand. According to Figure 191, the solar heat gain decreases more significantly in the cooling period than in the heating period.

Figure 192 compares the monthly heating and cooling energy demands of model building 2 with and without shading devices. It shows that the cooling energy demand of the building with shading devices is decreased through the implementation of shading devices. On the other hand, the heating energy demand increases slightly by installing shading devices. According to graphs 192 and 193, the total heating and cooling en-

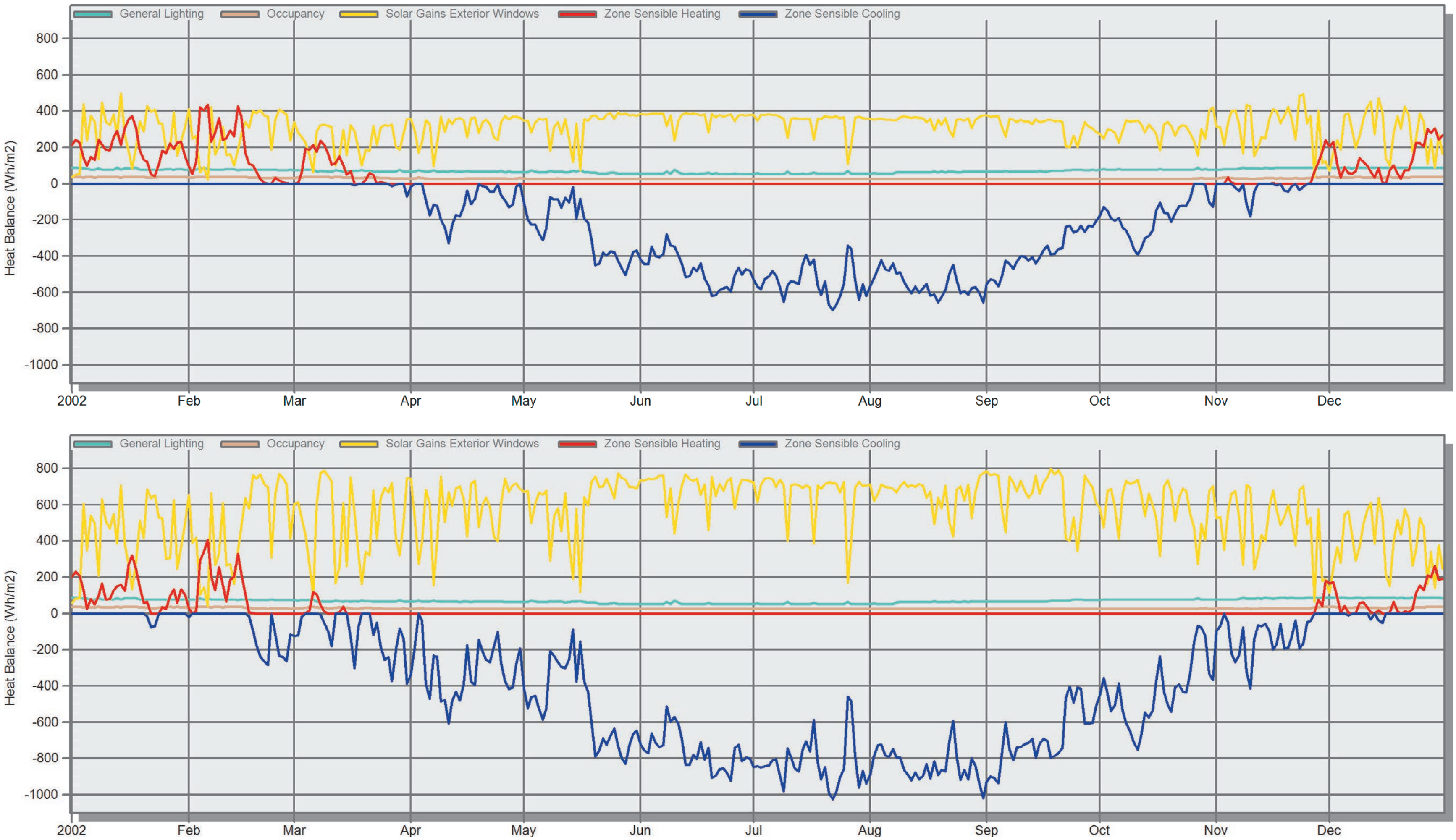
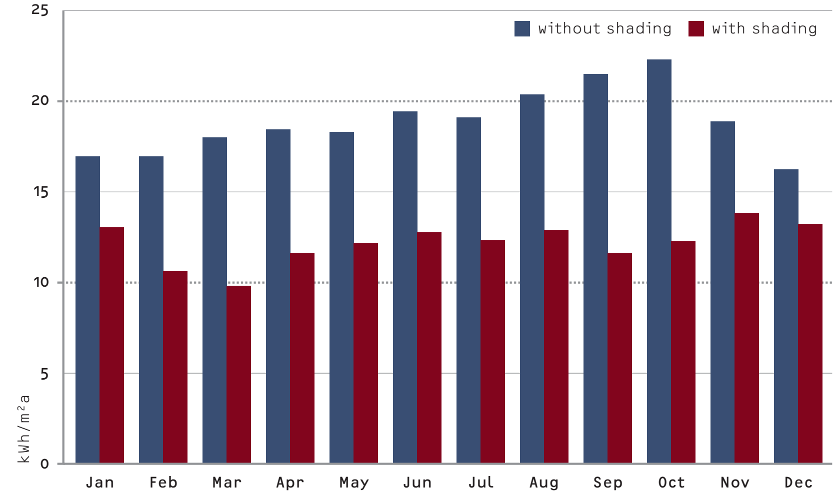


Fig. 194–195: Daily internal heat gains (solar heat gains and heating and cooling energy demand) of model building 2 with and without optimized shading devices (yellow: solar gains at windows, red: sensible heating, blue: sensible cooling, cyan: general lighting, pink: occupancy)

ergy demand and the primary energy demand for heating and cooling is decreased effectively by using shading devices at windows.

The application of shading devices has led to savings of 42.24% in the total heating and cooling energy demand and saving of 67.78% in the primary energy demand for heating and cooling.



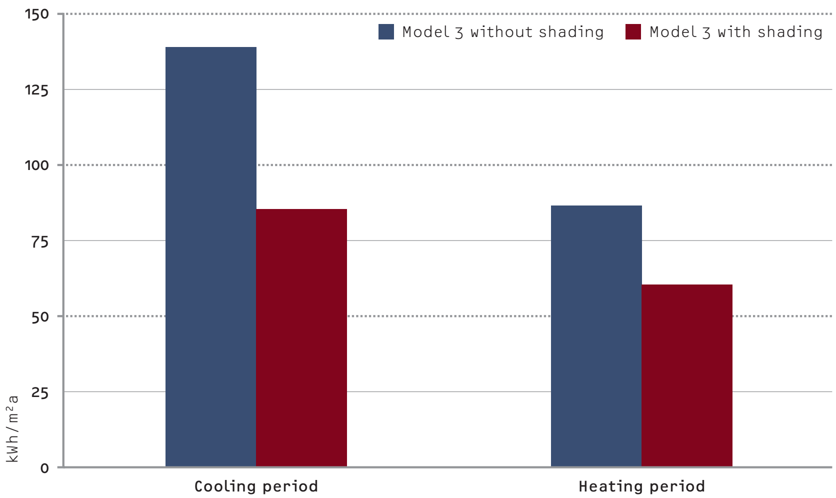
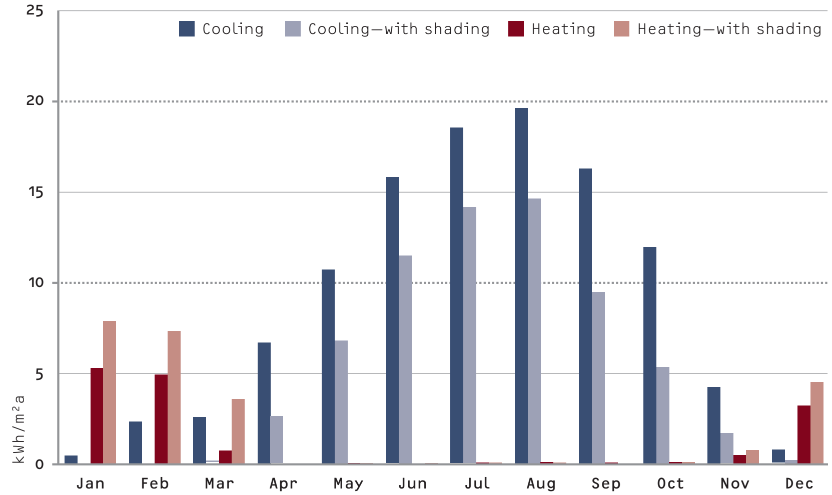


Fig. 196–197: Monthly solar heat gains (above) and solar heat gains in the heating and cooling periods (below) in model building 3 with and without optimized shading devices



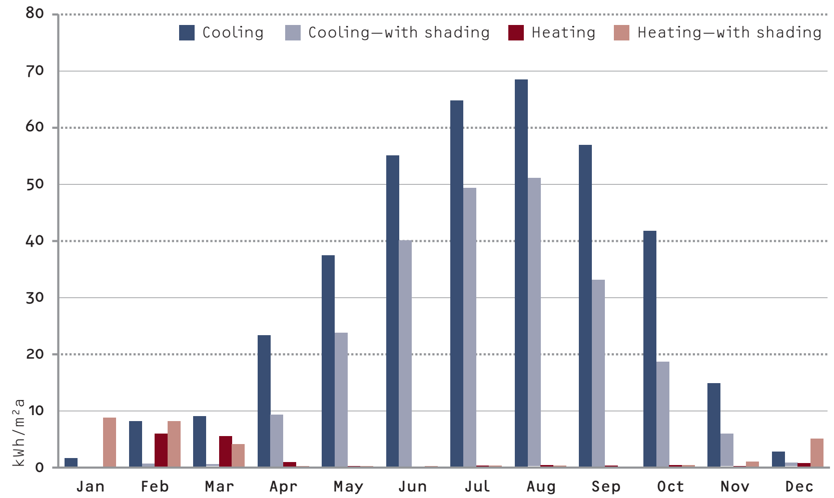


Fig. 198–199: Monthly heating and cooling (above) and monthly primary energy demand (below) of model building 3 with and without optimized shading devices

Model Building 3

A similar study for model building 3 shows that less solar energy penetrates this building with shading devices via windows, especially in the cooling period. This is illustrated in Figures 196 and 197. According to Figures 198 and 199, the cooling energy demand is lower than that in the building without shading devices. The shading devices decrease the solar heat gains in winter and, thus, increase the heating energy demand. The total energy demand of the building is decreased significantly by adding shading devices. The shading devices have led to a 37.22% reduction of the total heating and cooling demand and a 53.69% reduction of the primary energy demand.

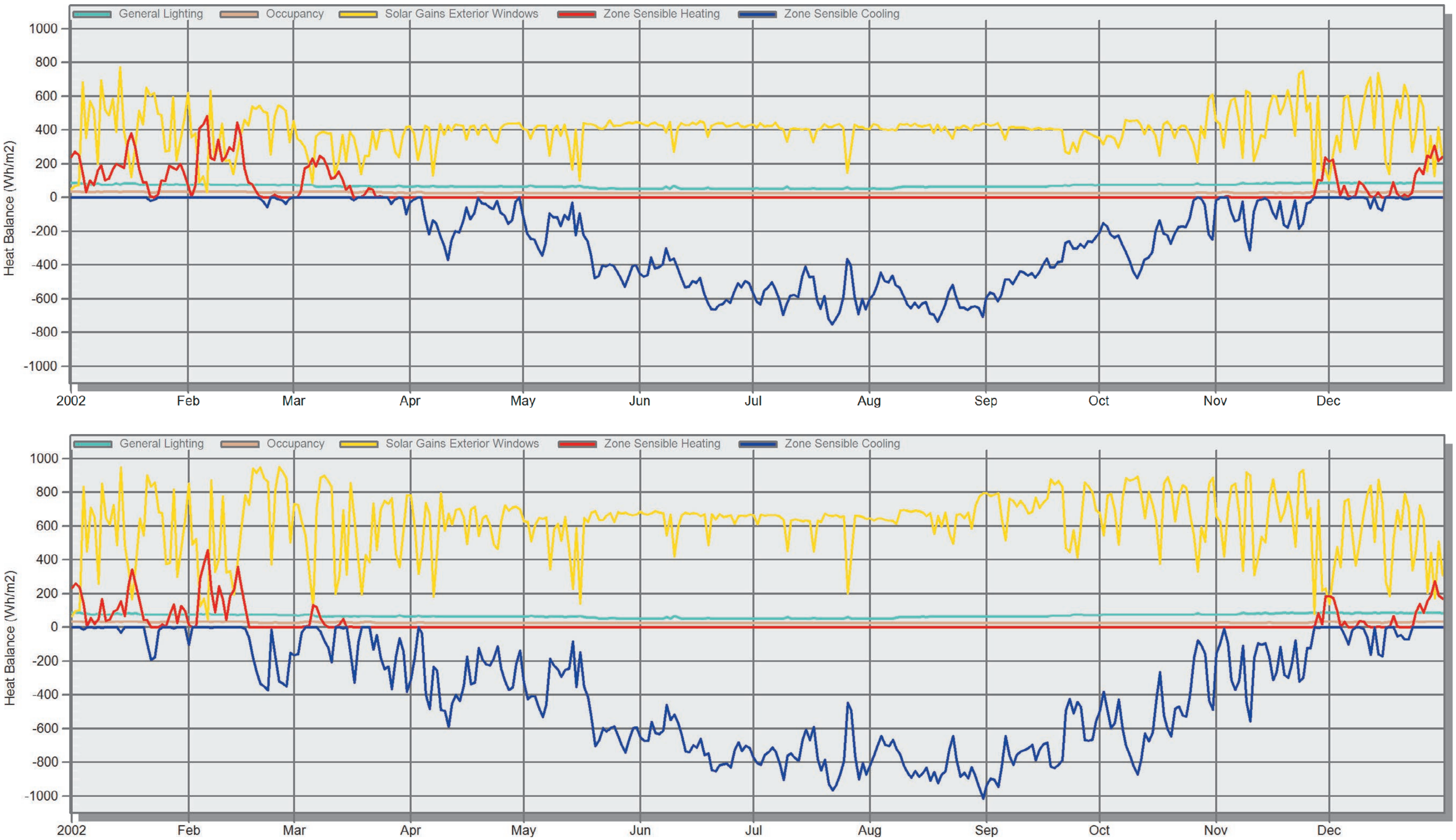


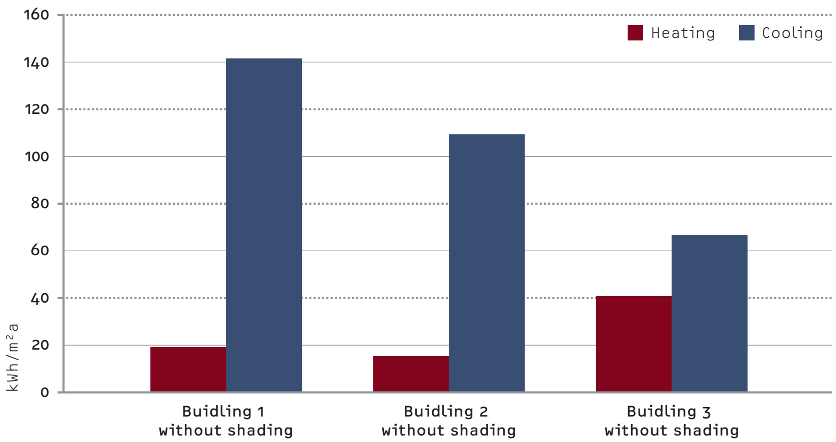
Fig. 200–201: Daily internal heat gains (solar heat gains and heating and cooling energy demand) of model building 3 with and without optimized shading devices (yellow: solar gains at windows, red: sensible heating, blue: sensible cooling, cyan: general lighting, pink: occupancy)

Analysis of the Effect of Building Elongation on the Building Energy Demand in Tehran

In order to study the influence of building elongation on the energy demand of buildings and understand how the energy-related factors are dependent on another, the three model buildings, which differ only in elongation, are compared under the same circumstances. The only variable factor of these three alternative buildings is, therefore, elongation. As Figure 202 presents, in the case of the buildings without shading devices, the building with the east-west elongation has the lowest cooling energy demand. That is because the building has shorter east and west-facing façades, and, thus, receives less solar radiation than other façades on summer mornings and afternoons from the low-latitude sun. The heating energy demand of the building with the square floor plan is the lowest and the building with the east-west elongation has the highest heating energy demand. Elongation affects the heating energy demand less than the cooling energy demand.

As presented in Figure 203, in the case of buildings with shading devices, the building with the square floor plan has the lowest cooling energy demand and the building with the south-north elongation the lowest heating energy demand.

Figure 204 illustrates the total heating and cooling energy demand of the buildings with their different elongations. In buildings without shading devices, the total heating and cooling energy demand is decreased by increasing the area of the south and north faces/windows in comparison to those in the east and west. This effect is due to the more beneficial solar heat gains of south façades/windows in comparison to those of east and west façades during both the heating and cooling periods. The behavior of buildings without shading devices changes by adding shading devices and reducing solar heat gain in summer, thus eliminating the negative effects of solar radiation. In the case of buildings with shading devices, the model building with equal south and east façades, the square floor plan building, has the lowest total heating and cooling energy demand.



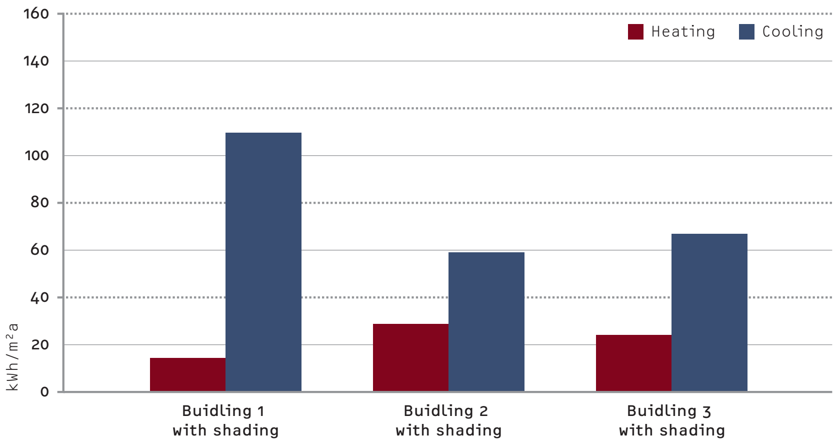
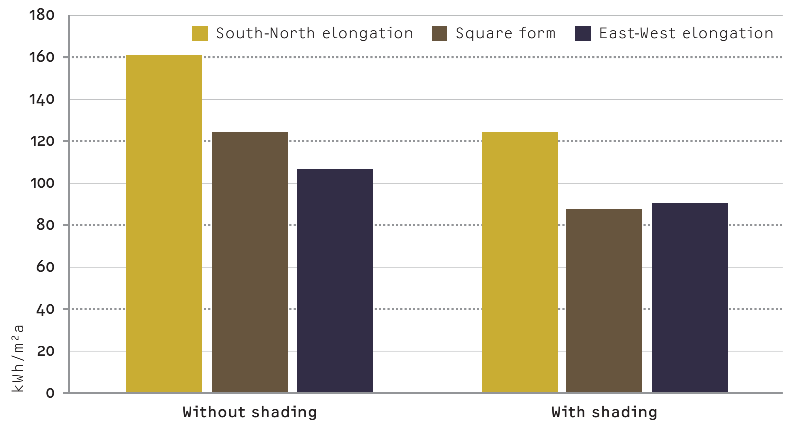


Fig. 202–203: Heating and cooling energy demand of buildings without (above) and with (below) optimized shading devices with different elongations



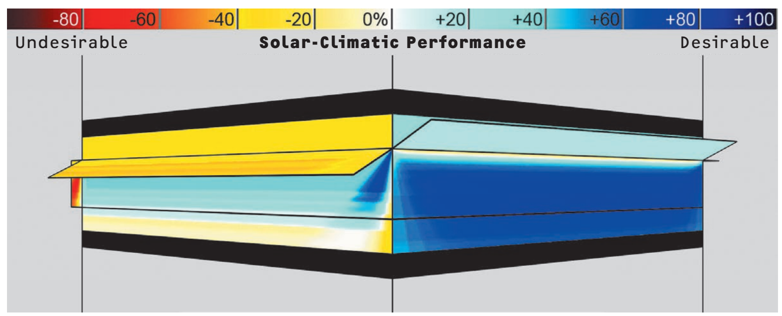


Fig. 204: Total heating and cooling energy demand of buildings with different elongations | Fig. 205: SOLARCHVISION design performance analysis of shading devices in Tehran, SW view, result: efficient elements

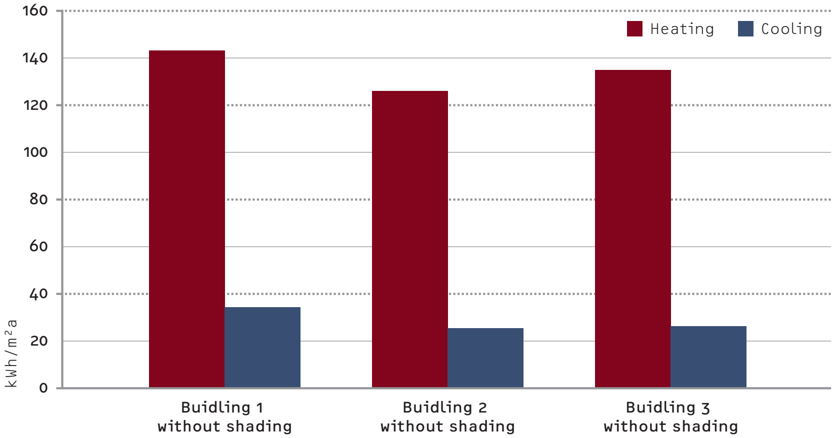
Analysis of the Same Models in another Climate (Munich)

Figure 206 compares the heating and cooling energy demands of the three model buildings without shading devices, which differ only in their elongation. According to the assumption that the buildings are located in Munich, Germany, with a cold climate, the energy demand for heating is much higher than that for cooling; the opposite is the case for Tehran. The model building with the square floor plan has both, minimum heating and cooling energy demand. This is the result of many parameters including, but not limited to, the simple fact that building 2 has less surface area than the two other narrower variations (Figure 183).

On the other hand, it is necessary to mention that the situation can change according to the solar-climatic properties of each location. For the case of Montréal in Canada, which is generally considered as a city with a cold climate, proper shading devices are more effective than in Munich, because there are more sunny days, a longer cooling period and warmer conditions in summer.

By applying the same shading devices in Munich as the ones that were optimized for Tehran's climate, the heating energy demand increases and the cooling energy demand decreases marginally. In the case of the buildings with shading devices, the square-shaped building has the lowest heating and cooling energy demand (Figure 207).

As is illustrated in Figure 208, the comparison of the total heating and cooling energy demand of the three buildings with and without shading devices shows that those with shading devices have a higher total energy demand. The diagram shows that the shading devices have a negative effect on the energy demand in Munich, despite leading to a reduction of the energy demand in Tehran. This is because the solar heat gains have an important role in reducing the building's energy demands in cold climates, like in Munich. The results also highlight that different climates require different strategies, e.g. different types and dimensions of shading devices. In the case of Tehran's climate, out of all buildings with and without shading devices and with different elongations, the buildings with the



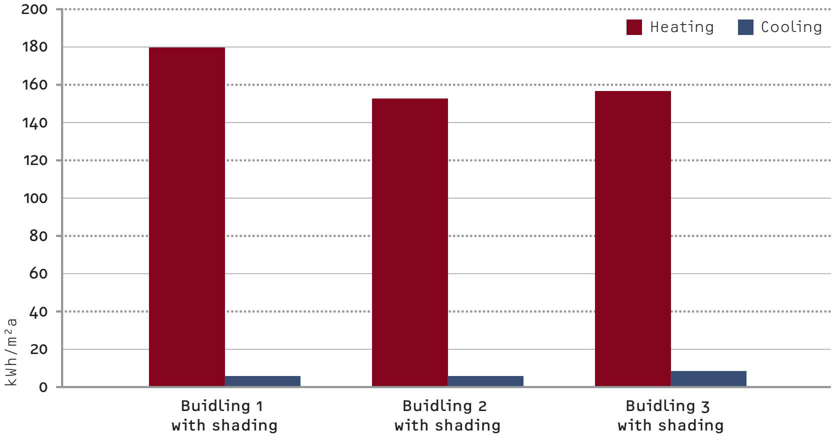
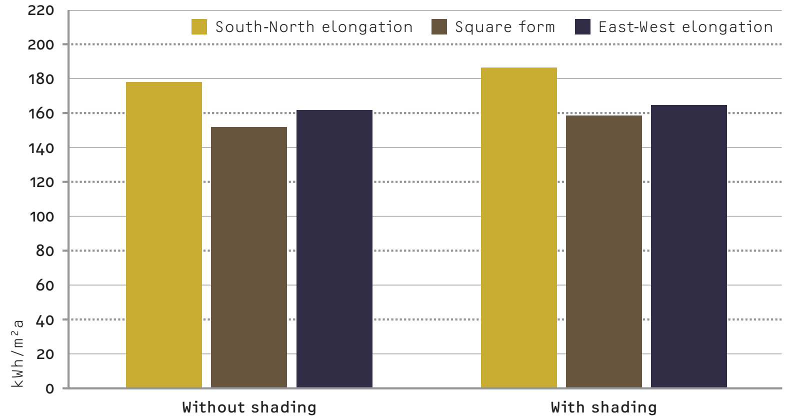


Fig. 206–207: Heating and cooling energy demand of buildings with (above) and without (below) shading devices with different elongations in Munich



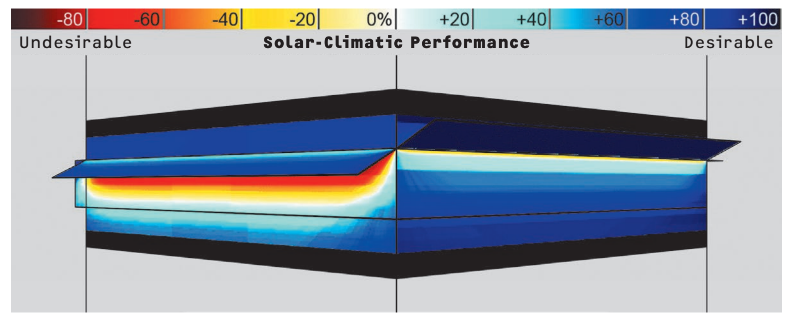


Fig. 208: Total heating and cooling energy demand of buildings with different elongations | Fig. 209: SOLARCHVISION design performance analysis of shading devices in Munich's climate, SW view, result: inefficient elements

best results were the ones with shading devices and a square floor plan. However, all variations perform much better with shading devices. The application of inefficient shading devices is not suitable for Munich, or anywhere else, simply because the performance of shading devices can be analyzed and improved by the SOLARCHVISION tool for each orientation and each climate individually (Figure 209).

Effect of Building Orientation on the Energy Demand of Buildings with Shading Devices in Tehran

In order to study the effect of orientation on the heating and cooling energy demands of buildings with and without shading devices, model building 3, which has the minimum total energy demand in the studied buildings, is simulated and compared for different orientations. In this study, the first orientation examined is true south as illustrated in Figure 183. If the main orientation changed, for example, to east, the building is rotated 90° counterclockwise without making any changes to the shading devices, to show only the effect of orientation. A considerable change would arise if the shading devices were changed at the same time as the orientation, as is discussed before.

As is presented in Figure 210, the heating energy demand of the buildings changes significantly with the orientation. The building has a minimum heating energy demand with a north orientation and a maximum energy demand with a 10° rotation south of east. The difference in the heating energy demand for different orientations is 35%.

According to Figure 211, the minimum cooling energy demand for the building occurs when it is oriented south. This is due to the low solar heat gains of south-facing windows in summer, as well as the proposed shading devices, which have been optimized to create sufficient shade at windows. The building has the same window area in the south and north façades and the vertical shading devices are designed and optimized for the north-facing windows; however, they cannot effectively reduce the solar heat gains during the cooling period when the building is rotated 180° (north orientation). They also produce a greater amount of undesirable shade during the heating period in comparison to the upward-tilted horizontal shading devices that are optimized for south-facing windows. Therefore, the heating energy demand of building with different orientations is at its lowest when facing north. This figure also shows that the building's maximum cooling energy demand is for a 10° rotation north of

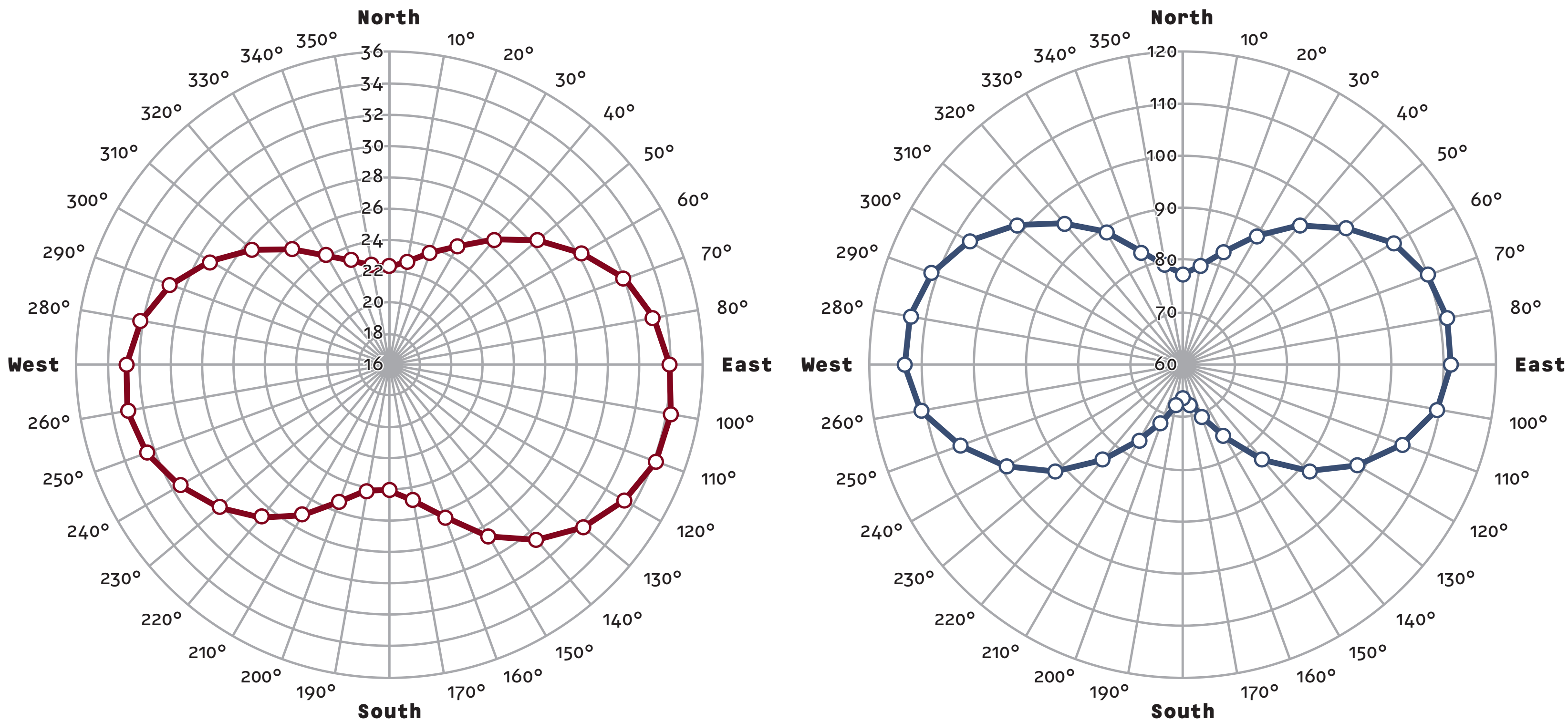


Fig. 210–211: Heating energy demand (left) and cooling energy demand (right) of model building 3 with south-optimized shading devices for different orientations

east; the demand is 41% higher than the minimum energy demand.

As illustrated in Figure 212 and 213, the minimum total heating and cooling energy demand, as well as the minimum primary energy demand, for the heating and cooling of model building 3 is for a south orientation. The maximum total energy demand, the worst situation, occurs with an east orientation and the maximum primary energy demand with a west orientation. The total and the primary energy demand for heating and cooling differs between 22–40% for the best and the worst orientations respectively. In order to achieve a better energy performance by a new orientation, the design of the shading devices has to be changed and improved.

The window-to-wall ratio in all cardinal directions equals 50%. A different window area in each façade of the narrow building, leads to dif-

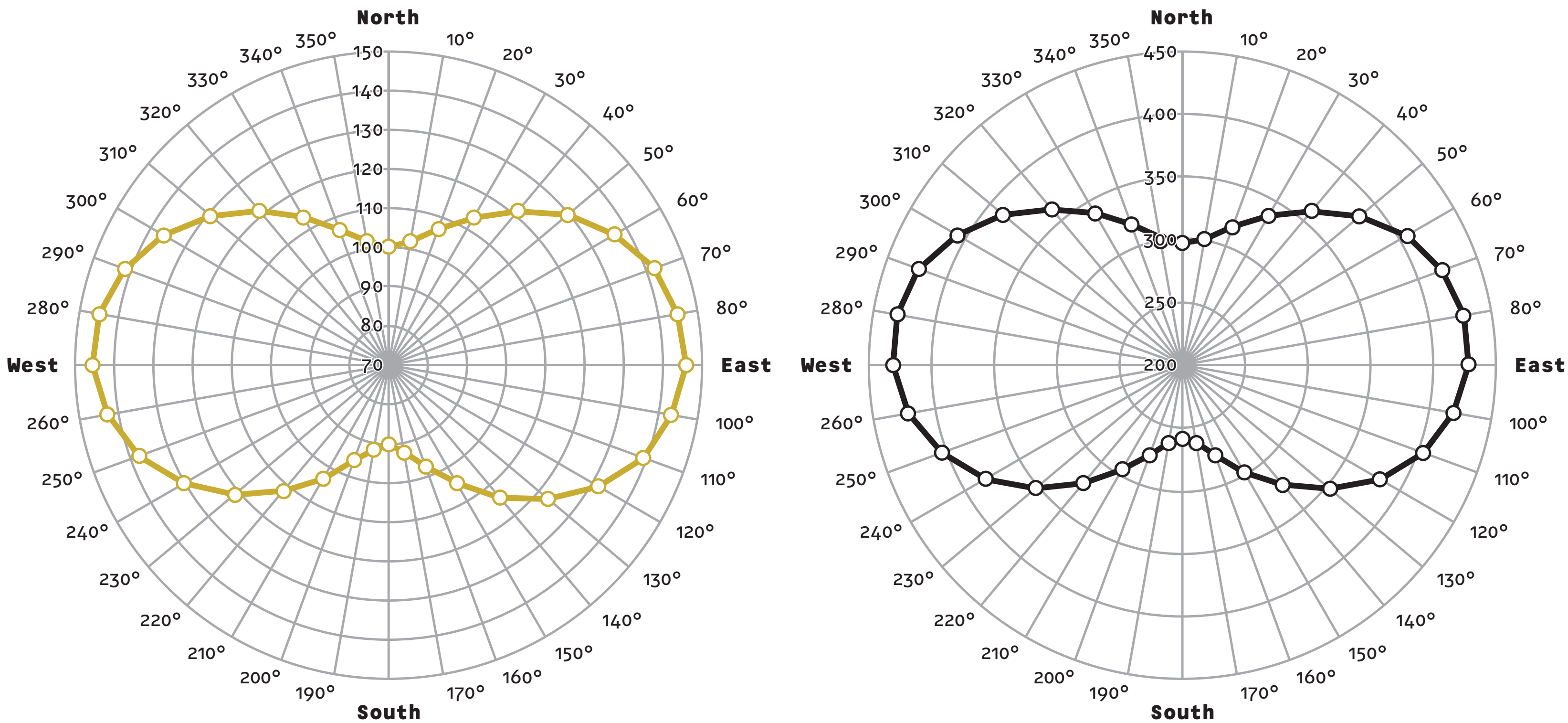


Fig. 212–213: Total heating and cooling energy demand (left) and primary energy demand (right) of model building 3 with south-optimized shading devices for different orientations

ferent energy demands than those presented here. However, the energy demand diagrams are not symmetric, not even for an east-west or north-south orientation. This unsymmetrical situation is due to the difference in shading devices. They are designed for their respective orientation. Rotation would lead to different amounts of solar heat gain and, thus, to different heating and cooling energy demands.

Effect of Building Orientation on the Energy Demand of Buildings without Shading Devices in Tehran

Model building 3, without shading devices, has the same low heating energy demands for a south and a north orientation in Tehran. The maximum heating energy demand occurs when the building is rotated 20° south of west or south of east. Because the window area in opposite façades is the same, the graph in Figure 214 is symmetric, and even the north orientation has a minimum heating energy demand. This highlights the fact that an optimum orientation depends on the window area in the cardinal directions. According to the analysis above, the best orientation in terms of energy efficiency has a 27% lower heating energy demand than the worst case.

The cooling energy demand, presented in Figure 215, is similar to the heating energy demand. The building with a true south and north orientation has the lowest cooling energy demand; the building with an east and west orientation has the highest cooling energy demand, which means a difference of 22%. The high cooling energy demand of the east and west orientation is due to the disadvantageous solar heat gains of the east and west-facing windows during the cooling period, as was discussed earlier for model building 1.

Consequently in hot and dry climates like Tehran, as well as warm climates, it is essential, if these orientations are chosen, to not only use shading devices but also to optimize them according to the movement of the sun in the sky, as was performed for model building 1.

For the total heating and cooling energy demand and the primary energy demand, as presented in Figures 216 and 217, the minimum energy demand occurs for a south orientation and the maximum for east and west orientations. Among the four cardinal directions, the south-facing façade has the most advantageous solar heat gains. The solar heat gains are high in the heating period and low in the cooling period. Thus, the south-oriented building has the minimum total and primary energy demand. If the orientation of the building changes, the total and primary energy demand increases by 23% and 22% respectively.

A comparison between the results from this section and the results deriving from the SOLARCHVISION method illustrates a number of similarities and demonstrates the extreme effects of the sun, the climate and the architectural design on the building's heating and cooling energy demand (Figures 119, 180 and Table 4).

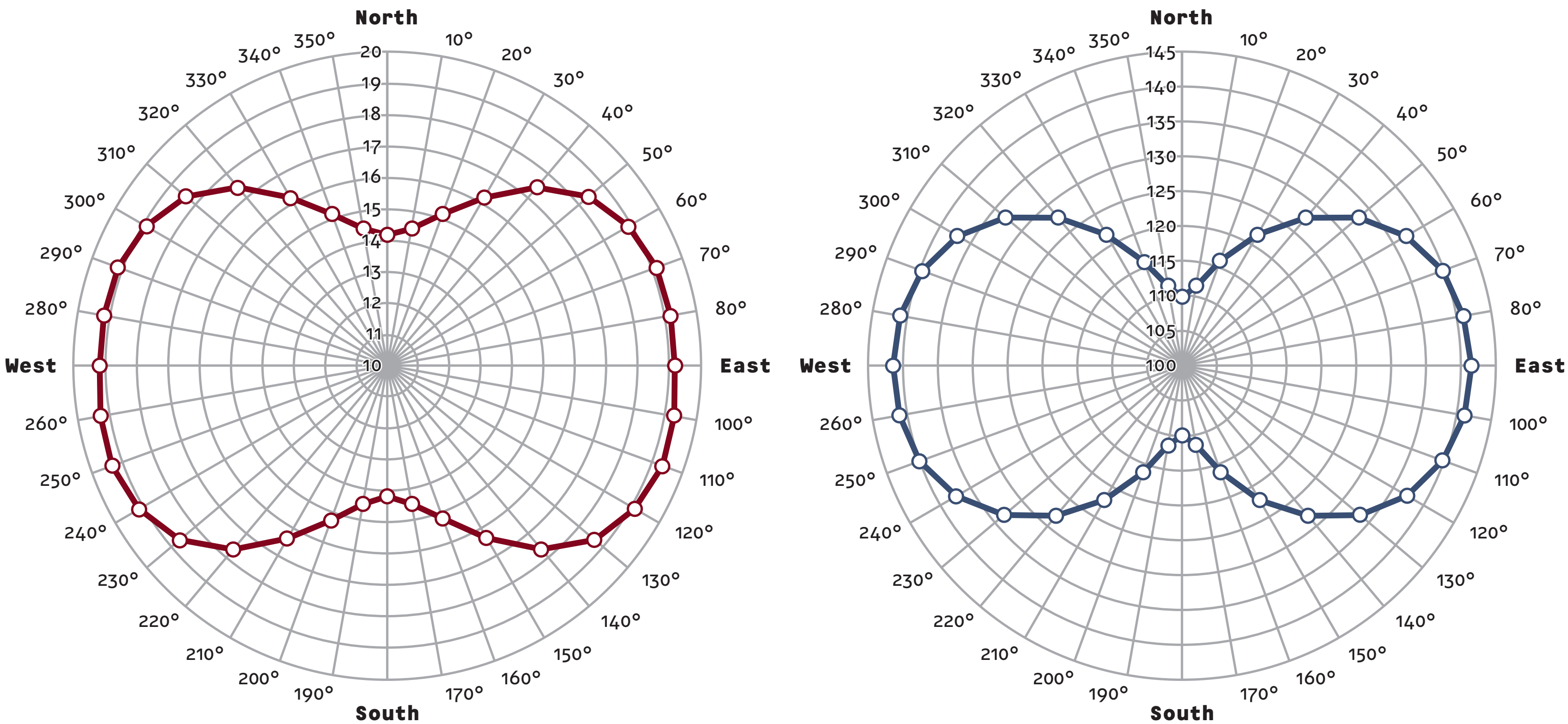


Fig. 214–215: Heating energy demand (left) and cooling energy demand (right) of model building 3 without shading devices in different orientations

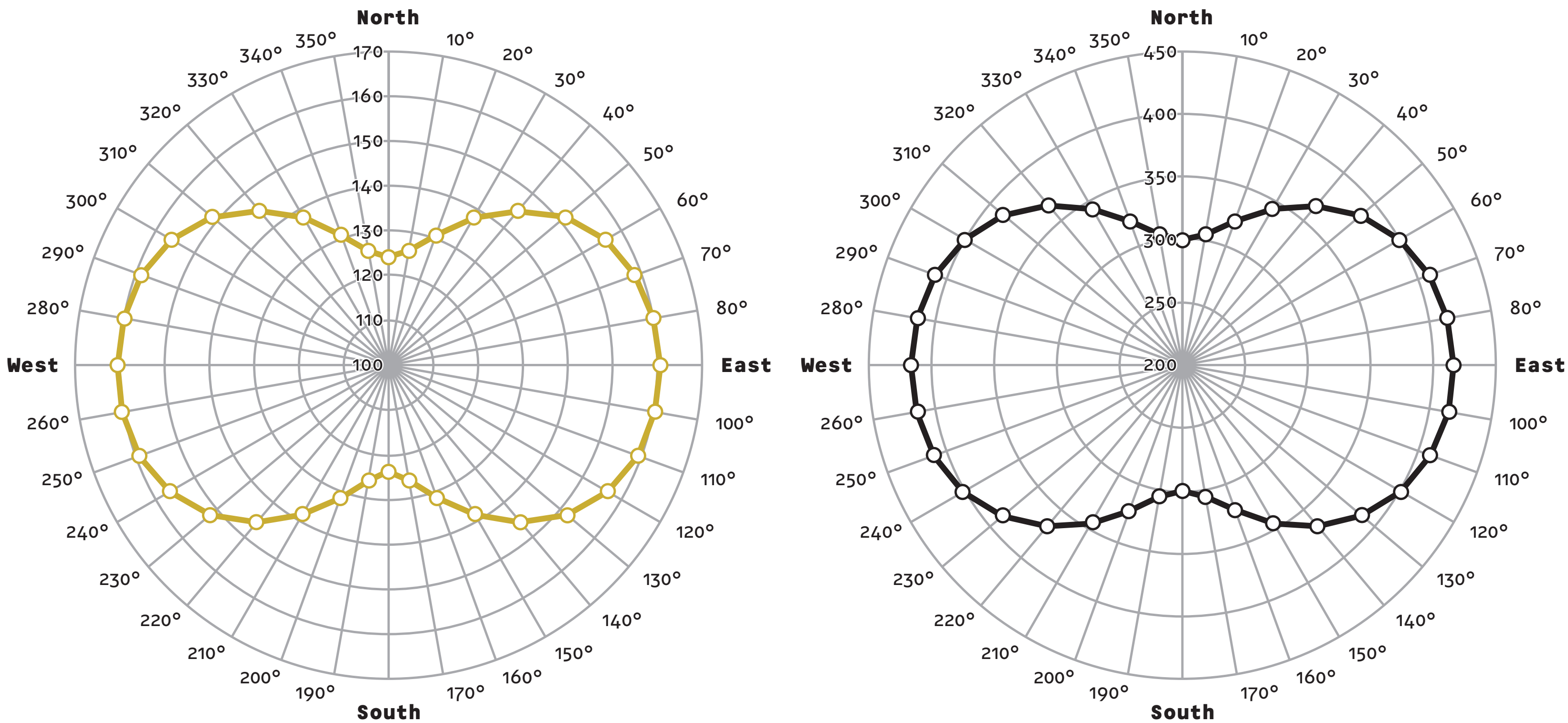


Fig. 216–217: Total heating and cooling energy demand (left) and primary energy demand (right) of model building 3 without shading devices in different orientations

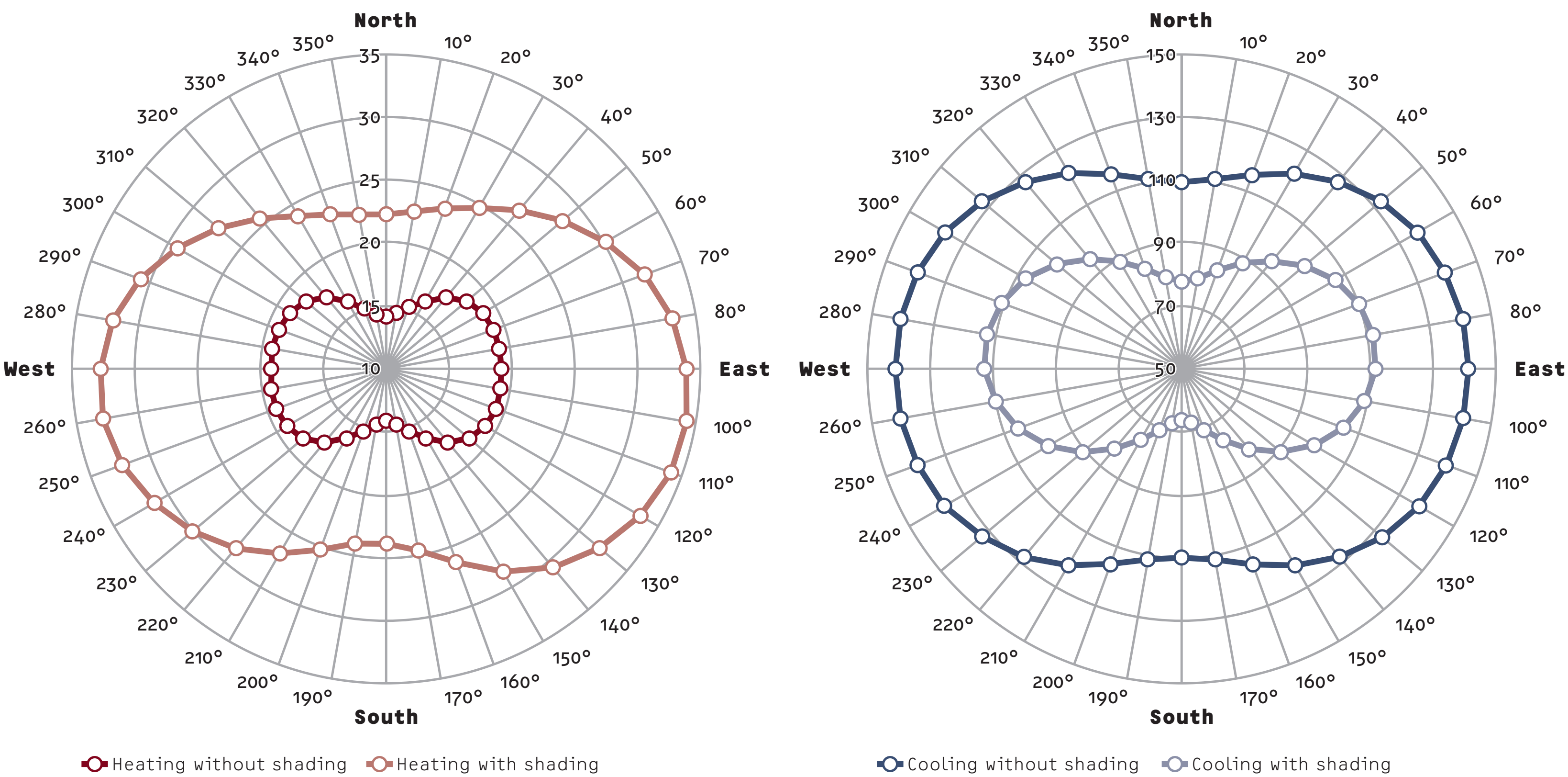


Fig. 218–219: Comparison of heating energy demands (left) and cooling energy demands (right) in model building 3 in different orientations with and without shading devices

Effect of Orientation in Buildings with and without Shading Devices
Figure 218 compares the heating energy demand of model building 3 with and without shading devices for different orientations. It is necessary to mention again that the shading devices for the different façades of the model building were not optimized after rotating the building; they were only improved for the first frame, as is illustrated in Figure 183. According to the graph, the heating energy demand of the building with shading devices is higher in all orientations than that without shading devices. The behavior of the heating energy demand is similar, but not the same. The buildings with and without shading devices react differently according to their orientation.

The cooling energy demand is lower in different orientations for the building with shading devices. However, the behavior of the cooling energy demand is not entirely the same for the building with and without

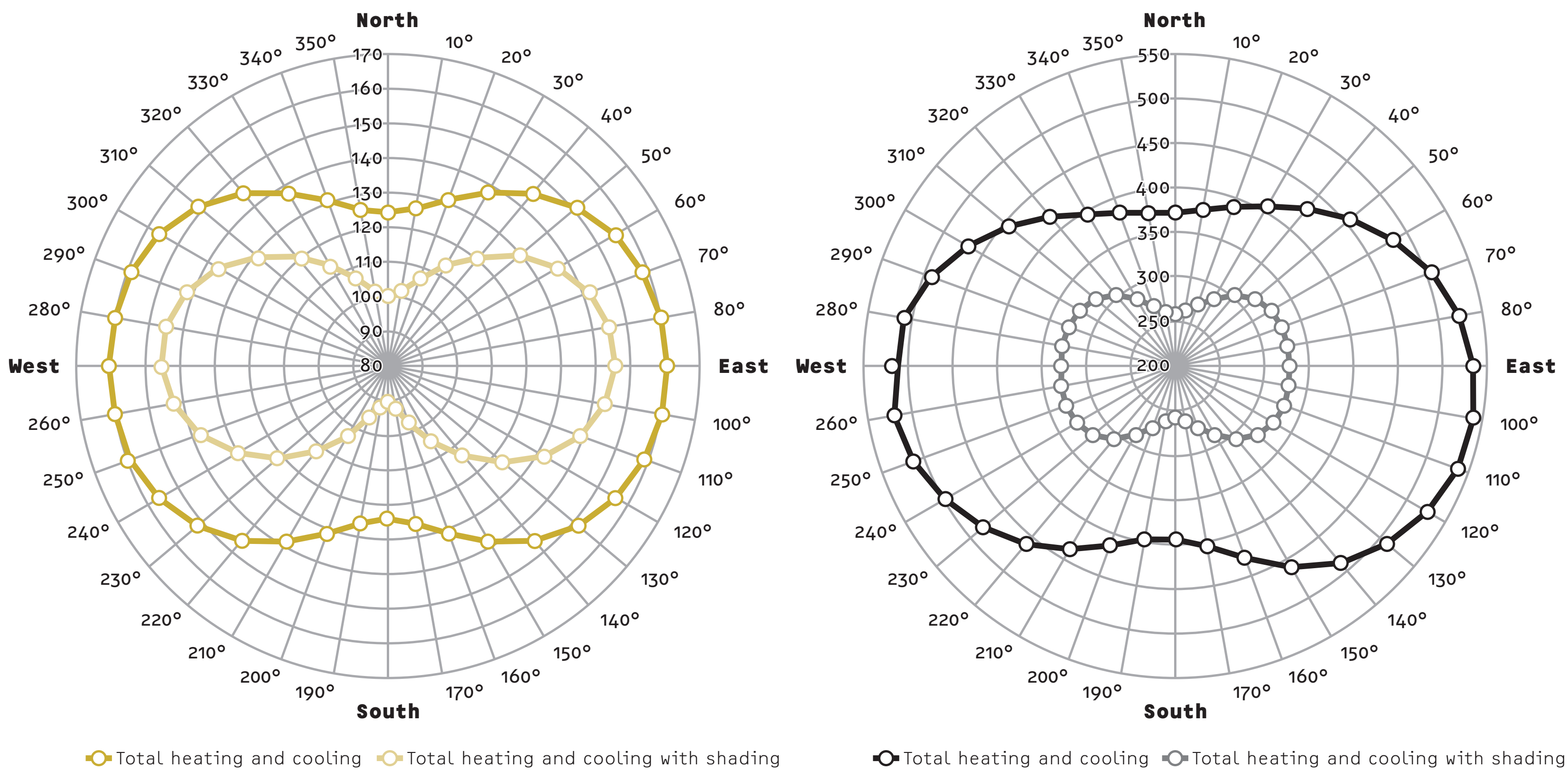


Fig. 220–221: Comparison of heating and cooling energy demand (left) and primary energy demand (right) of model building 3 in different orientations with and without shading devices

shading devices due to the fact that all energy-related factors are dependent on one another.

According to Figures 220 and 221, the total heating and cooling energy demand and the primary energy demand is lower in all orientations for the building with shading devices. The behavior of the total and the primary energy demand regarding orientation is similar, but not the same.

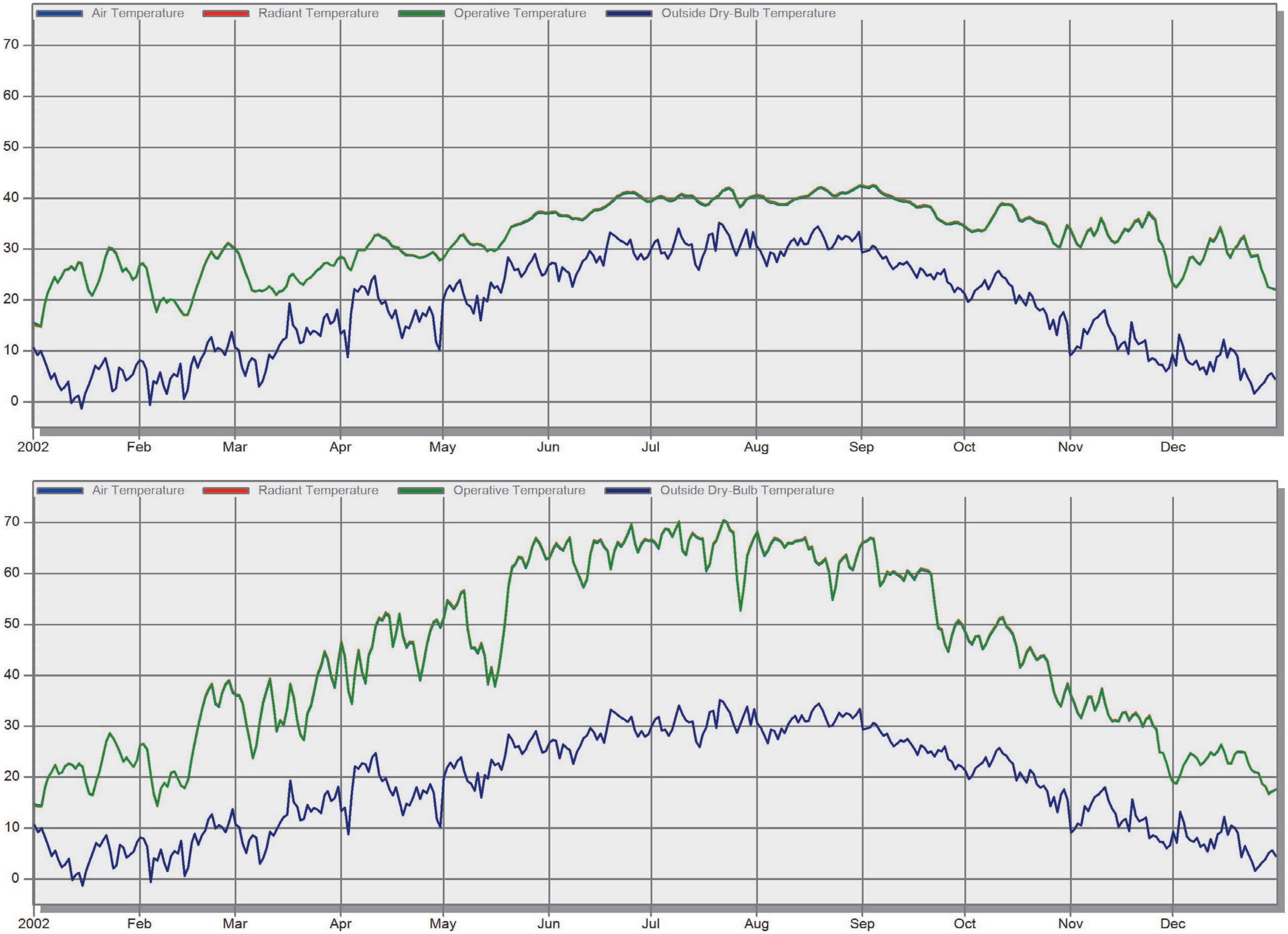


Fig. 222–223: Daily internal and external air temperatures in two solar-optimized and non-optimized buildings (°C)

Solar Heat Gain and Internal Comfort Index

In order to illustrate the importance and the relation between the architectural design, the sun and the climate in general and to ensure indoor thermal comfort through both heating and cooling, partially or in total, two exemplary buildings located in the solar and climate conditions of Tehran are compared. The two buildings are three-story, one-zone residential buildings, which are identical in dimension and material. There is only a difference between the factors affecting the amount of solar heat gain, including different orientations, window surface area and fixed shading devices. In one building, the design takes account of the solar gains to fulfil the requirements during the heating and cooling period and is improved accordingly; the other building is designed without paying any attention to the solar conditions. In order to illustrate the direct effects of the sun on the internal thermal conditions, the internal tempera-

Fig. 224-225: Daily comfort indices in solar-optimized and non-optimized building

tures, and comfort indices are studied. The buildings are not equipped with any heating or cooling systems; thus, no additional artificial heat or cold is delivered to the buildings internally.

The following figures compare the internal temperature in the two buildings. Figures 222 and 223 present the internal and external air temperatures within the two buildings built using the same construction materials. The first diagram refers to the building which is not designed according to the optimum use of solar radiation in summer and winter. The second part of the graph refers to the same building, however, including some changes to express the dependence on solar radiation. According to the graphs, the internal air temperature in the first building is much higher in summer than that in the second building. The internal temperature in the non-optimized building is higher than 60°C for about four months and even reaches 70°C.

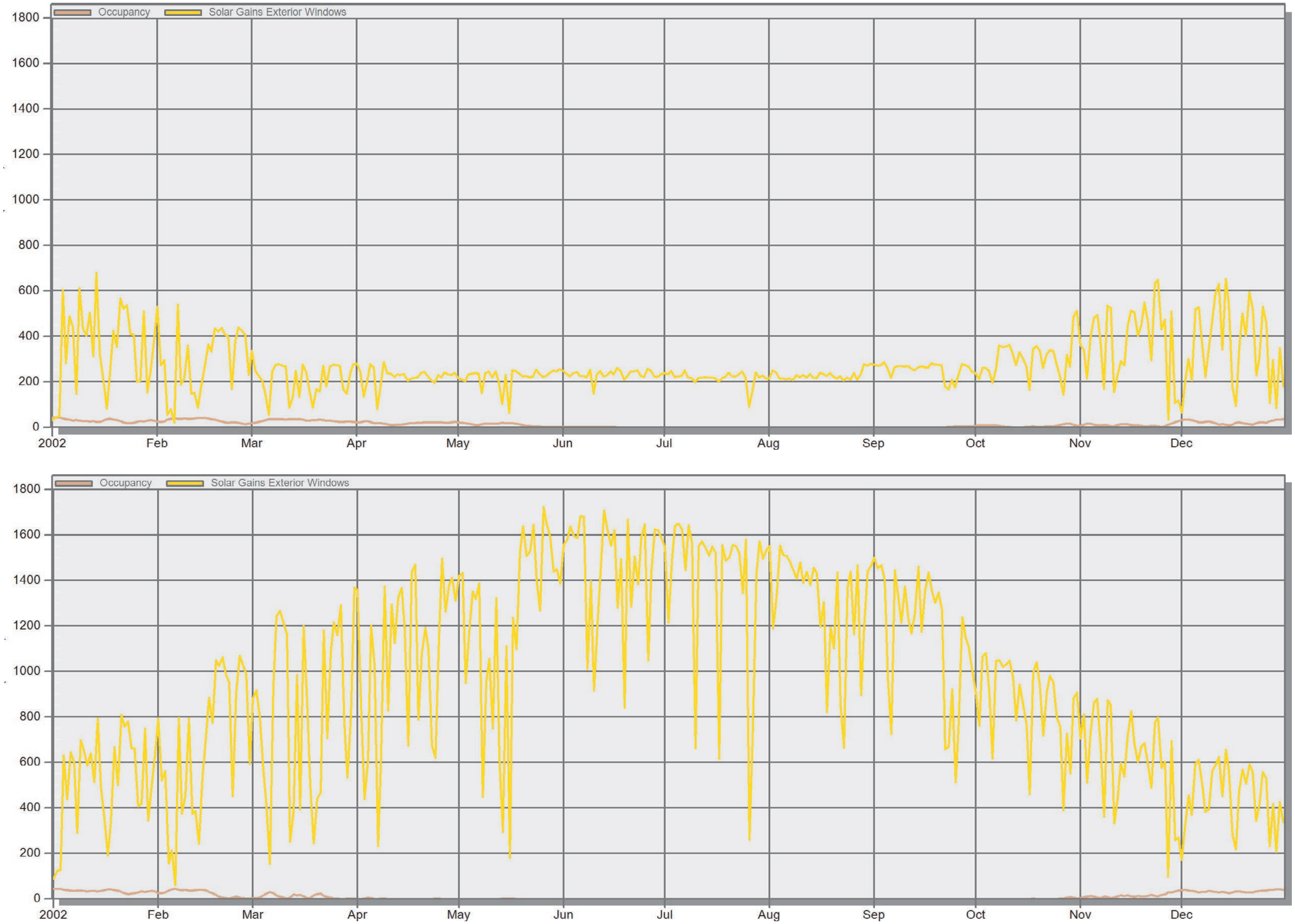


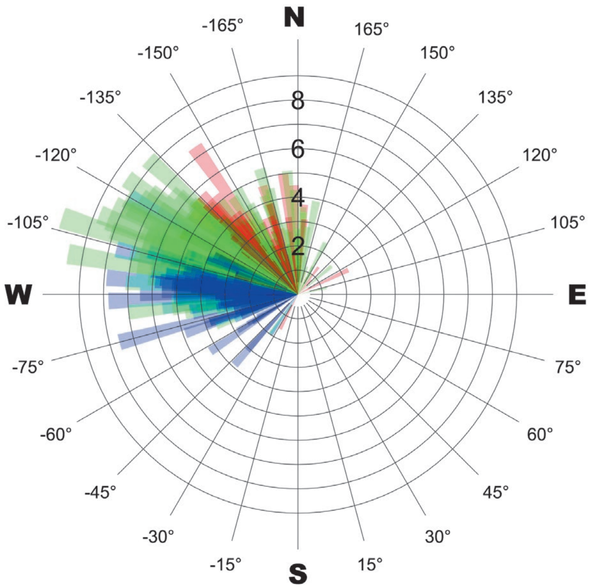
Fig. 226–227: Daily solar heat gains in the solar-optimized and non-optimized buildings (kWh/m²)

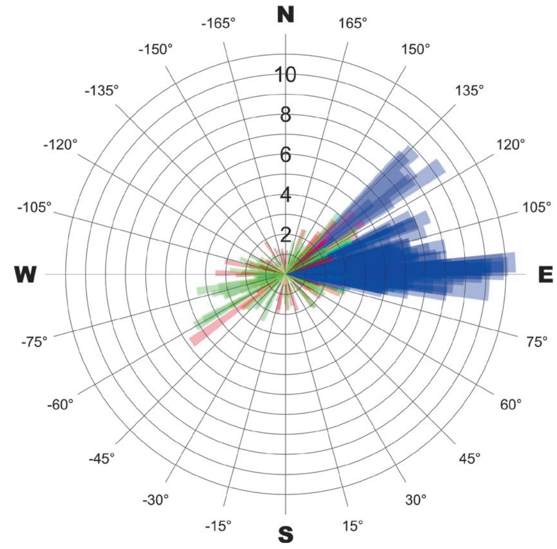
The situation in the building that is changed to suit the amount of required solar radiation in summer and winter is much better. The air temperature in this building is about 40°C in summer, in the period during which the air temperature in the non-optimized building is between 60 and 70°C. In order to reach comfortable thermal conditions in the non-optimized building, a high amount of cooling energy must be consumed to reduce the high internal temperature. This amount is much less in the second building. A similar situation applies for reaching comfortable conditions in the heating period.

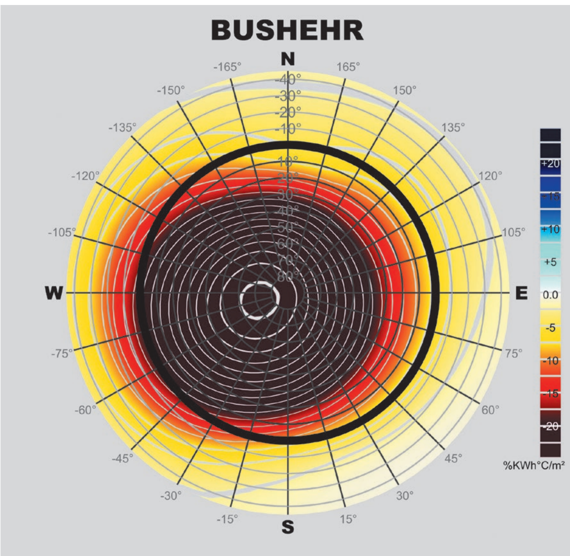
Fig. 228: Narrow alley in the dry climate of Yazd, Iran (Hossein Farahani)

Fig. 229: Improving ventilation in the urban fabric of the hot and humid city of Bushehr, Iran (Hossein Farahani)

Today, the proper response to the different conditions of each location, including but not limited to climate factors, such as the sun and the wind, is a complex task which must be considered throughout the planning process of new villages and cities. However, there are a number of traditional cities and villages around the world able of providing valuable lessons concerning the integration of a climatic-responsive vision on a variety of scales within architecture. For this reason, it is important to study urban fabrics carefully, in addition to passive houses.







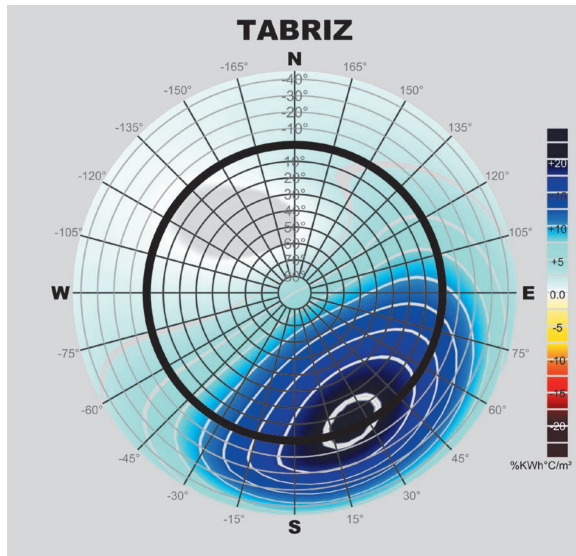


Fig. 230–231: Direction and speed (in knots) of the prevailing winds in Bushehr (upper left) and Tabriz (upper right) between 1951 and 2005, red: summer, blue: winter, green: spring & autumn
Fig. 232–233: SOLARCHVISION passive analysis of different surfaces and inclinations (from -45° to 90°) for Bushehr (lower left) and Tabriz (lower right)

The diagrams above illustrate the effects of the wind and sun in different orientations for two cities in Iran. In consideration of the analysis carried through by SOLARCHVISION for Bushehr, a wide range of directions, from N.W. to south, are unfavorable for solar radiation throughout the year. The orientations between N.W. and west are also on the path of the prevailing winds during different months of the year. As a result, these orientations can be considered the best alternatives to be opened to the wind and not the sun. Another complex situation is illustrated by the cold climate of Tabriz, where cold winds in winter can decrease the level of comfort in east/west-oriented streets if there are rows of building volumes oriented south to increase the energy-efficiency of buildings.

Figures 234–237 illustrating the solar-climatic performance of alternative arrangements in three different climates (Tehran, Abu Dhabi and Montréal) demonstrate that the comfort level of the urban spaces between

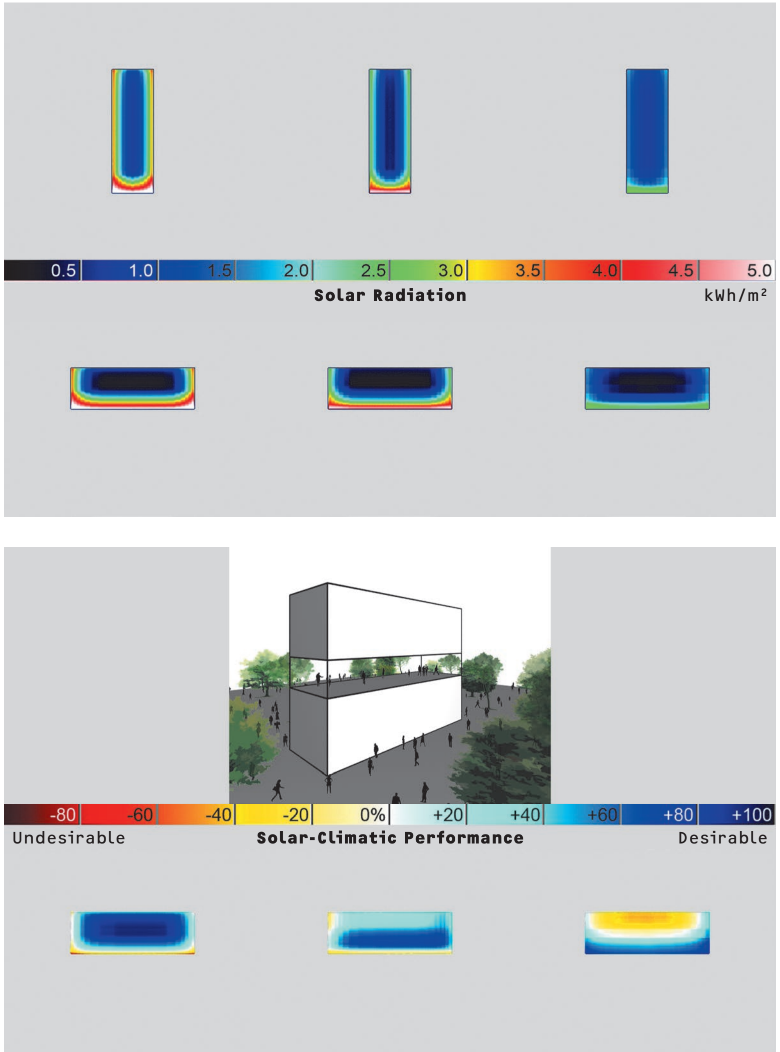


Fig. 234–235: Indoor Solar Radiation Model (above) and SOLARCHVISION analysis (below) for a south-oriented space (24 m x 8 m, h = 3 m), left: Abu Dhabi, middle: Tehran, right: Montréal

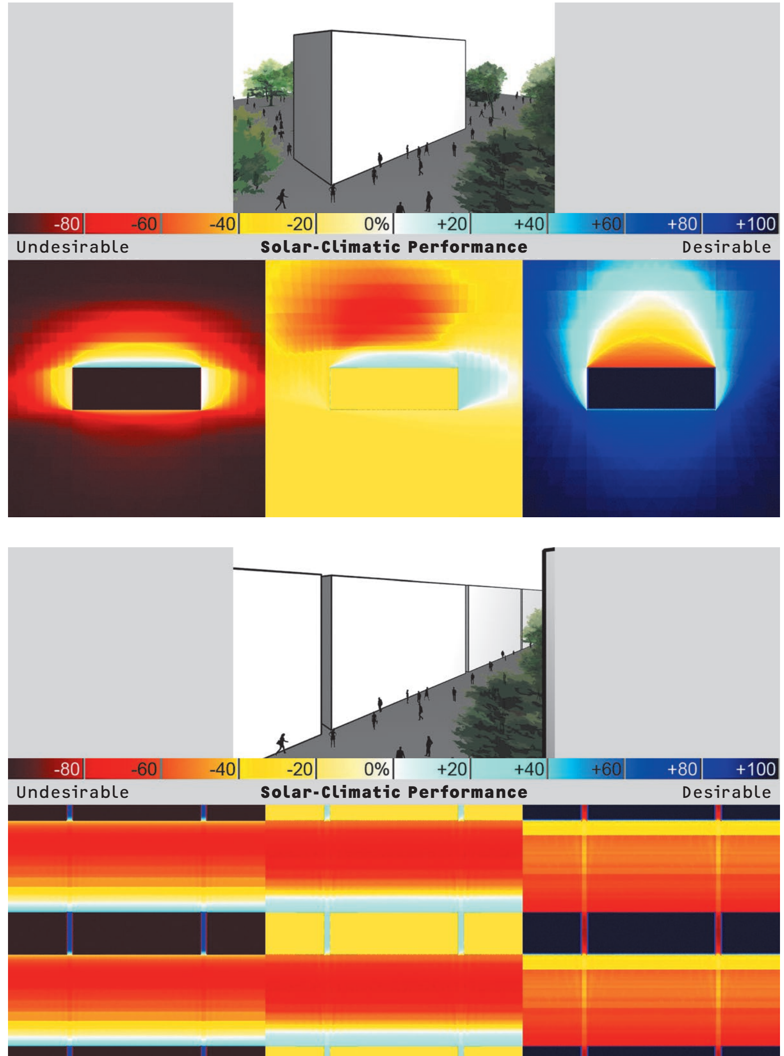


Fig. 236–237: Outdoor SOLARCHVISION analysis for south-oriented single and multi-story buildings (center to center distance = 25 m), left: Abu Dhabi, middle: Tehran, right: Montréal

the blocks decreases significantly by shaping the building mass to achieve a better orientation (between south and S.E.) in terms of energy efficiency.

This is simply because the building volumes receive the most favorable energy from the sun in cold periods and do not block out most of the unfavorable radiation in hot periods. However, the comfort level at undesirable points in the urban fabric, which are presented in red, can be improved by using trees and secondary structures (such as shading and reflecting devices). Enhanced optimization of the orientation and form on the site should be considered as one of the main objectives of a solar-climatic design for new urban fabric. This is important because there are numerous practical opportunities to improve the performance of each building orientation in comparison to the situation of the existing urban fabric. Furthermore, urban decisions are long-lasting and affect not only the environment but also human health, comfort and safety for extended periods of time.

In consideration of Figure 237 of south-oriented multi-story buildings, it is a wise idea to shift the axis of east/west-oriented roads to the south in cold climates to provide wider pedestrian areas on the north side with better conditions due to more sunshine. In contrast, in hot climates, by moving this axis to the north, a wider pedestrian area is created on the south side, which is better in terms of shade. In both of these examples, the main idea is to use the areas with poor solar-climatic performance for cars and not for walking or cycling. Using rows of trees on the north side of east/west-oriented roads can also create more comfortable areas in all of these climates (in the northern hemisphere).

Instead of narrow south-oriented buildings, as analyzed above, the studies on cubic volumes below with more space around the perimeter show that, by changing the proportions and orientation, the situation of open spaces between blocks can be improved for different warmer and colder climates. It is important to understand that the volume, floor area and building coverage is identical in the alternatives above.

On the other hand, in hot climates, increased proportions of the urban fabric in the Z-axis lead to better conditions. In contrast, in cold climates, decreased proportions in the Z-axis produce similar improvements as those in the Figure 239.

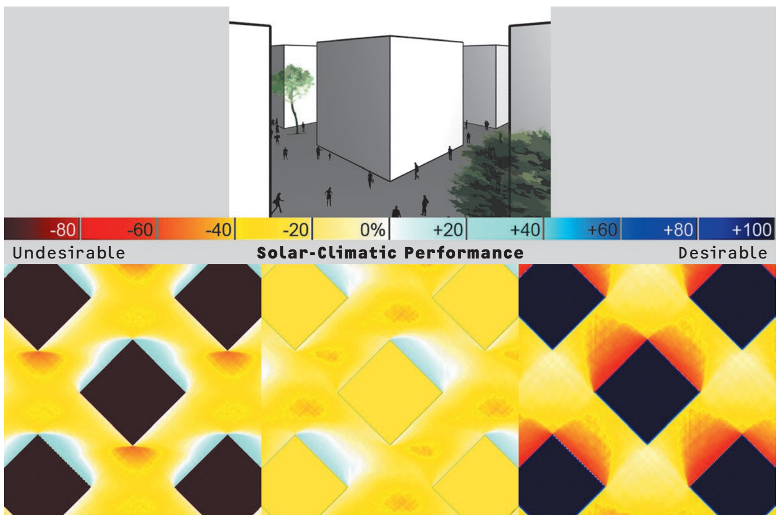


Fig. 238: Outdoor SOLARCHVISION analysis for multi-story buildings (14 m x 14 m, h = 14 m, center to center distance = 25 m), left: Abu Dhabi, middle: Tehran, right: Montréal

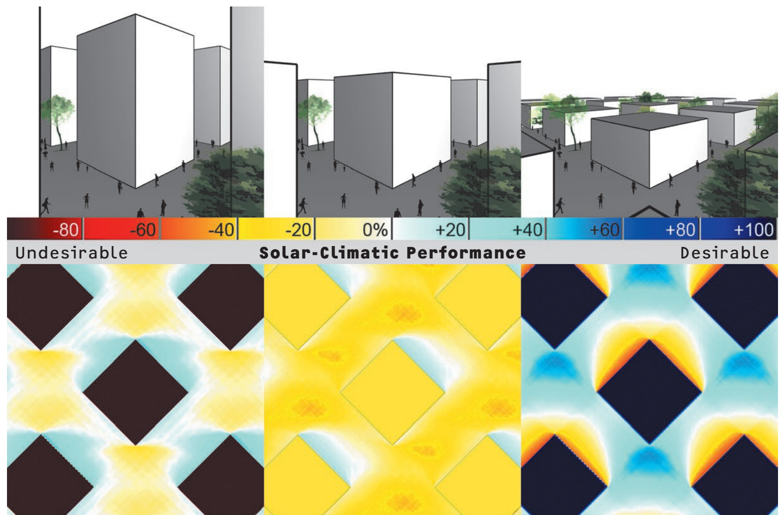


Fig. 239: Outdoor SOLARCHVISION analysis for multi-story buildings (14 m x 14 m), left: Abu Dhabi (h = 21 m), middle: Tehran (h = 14 m), right: Montréal (h = 7 m)

It is also necessary to mention that it is not always a good idea to increase the height and build taller and denser buildings in hot climates to improve the solar-climatic performance of the urban fabric. There are better solutions available to produce comfortable shade in open spaces, e.g. planting trees, membrane structures, etc.

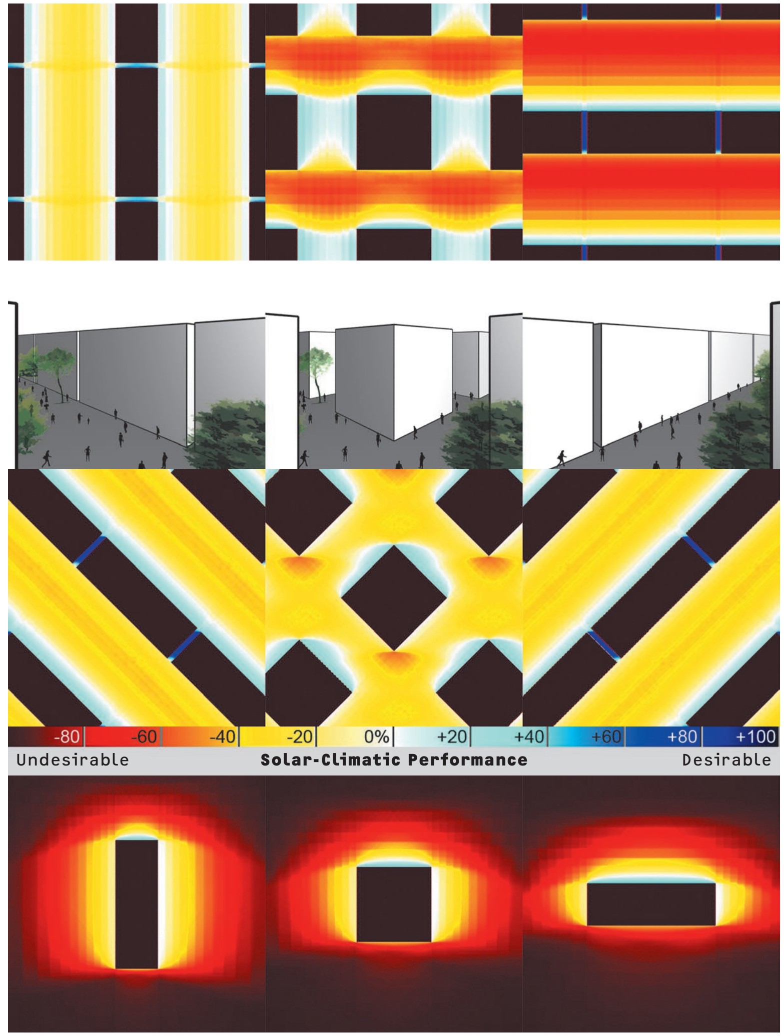
The next pages illustrate some studies using the solar-climatic performance analysis for open urban spaces in three different climates. In addition to the variety of alternatives presented here for each project, there are other alternatives which should be analyzed in a similar way. The presented diagrams can be studied in isolation or in comparison with others to determine better solutions at the early design stage. Similar analyses should be performed from the concept design to detail design stage to achieve an integrated solar-climatic design. The following graphs show how the changes in proportion and direction of a cubic building can affect the comfort conditions of the space around the building volume as well as in the interior. In general, in order to select an acceptable alternative, several aspects have to be considered simultaneously (e.g. architectural, structural, construction, daylighting, etc.). In this way, it is possible to select the alternative which provides the most acceptable conditions, both inside and outside, not only from a solar-climatic point of view but also in terms of other considerations. In any case, the selected alternatives should be optimized in terms of the sun and the climate to enhance energy-efficiency and daylight conditions. Furthermore, they should be improved to maximize the benefits for health, comfort and safety for all people, whether inside or outside, and minimize the negative effects on the environment.

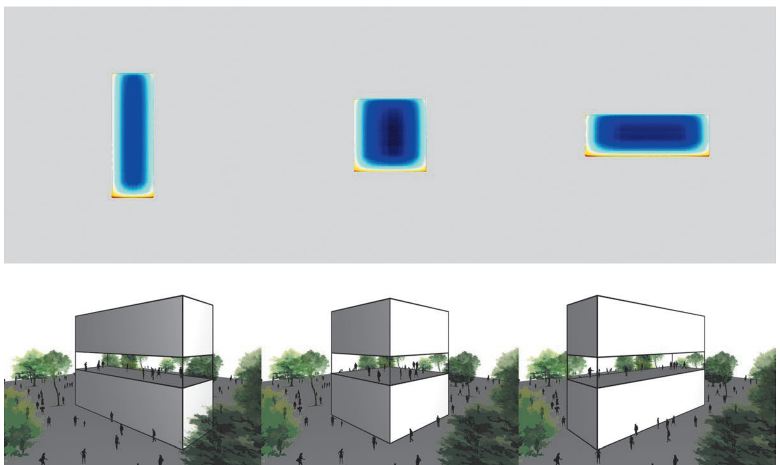
4.1 Design in Hot Climate (Abu Dhabi)

The analysis presented here illustrates the solar-climatic performance of some alternatives with different orientations and proportions in Abu Dhabi. Due to the similar climatic conditions in a number of cities around the Persian Gulf, this analysis is also useful for other coasts in the region: e.g. Doha in Qatar, Dubai and Sharjah in UAE, Dammam in Saudi Arabia, Bahrain, Kuwait and many Persian coasts and islands. However, if precise climatic information were applied for each of these cities, a slight change would appear in the results.

In regard of the SOLARCHVISION outdoor analysis of a single volume, a better condition is created on the east side of the building volume in comparison to that on the west, north and south throughout the whole year. Similarly, the situation of outdoor areas near the N.E. and N.W. sides is better in comparison to that near the S.E. and S.W. Nevertheless, the level of comfort in open spaces around the building can be improved in all directions by using shading devices as well as trees according to the results from similar analyses performed in advance.

It is also worth noting again that the energy from the sun is the best source of energy in hot climates, which can be used in the building for mechanical cooling and electrical systems. This concept can definitely help to combat local and global problems, such as the heat island effect, pollution and global warming. Thus, undesirable radiation on roofs should be considered as a positive potential for locating solar collectors and PVs.





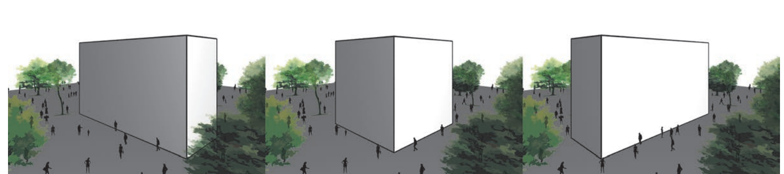
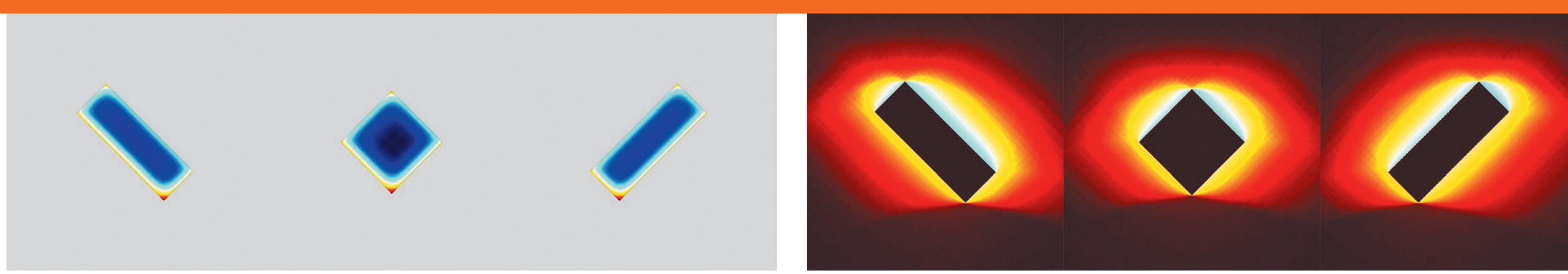
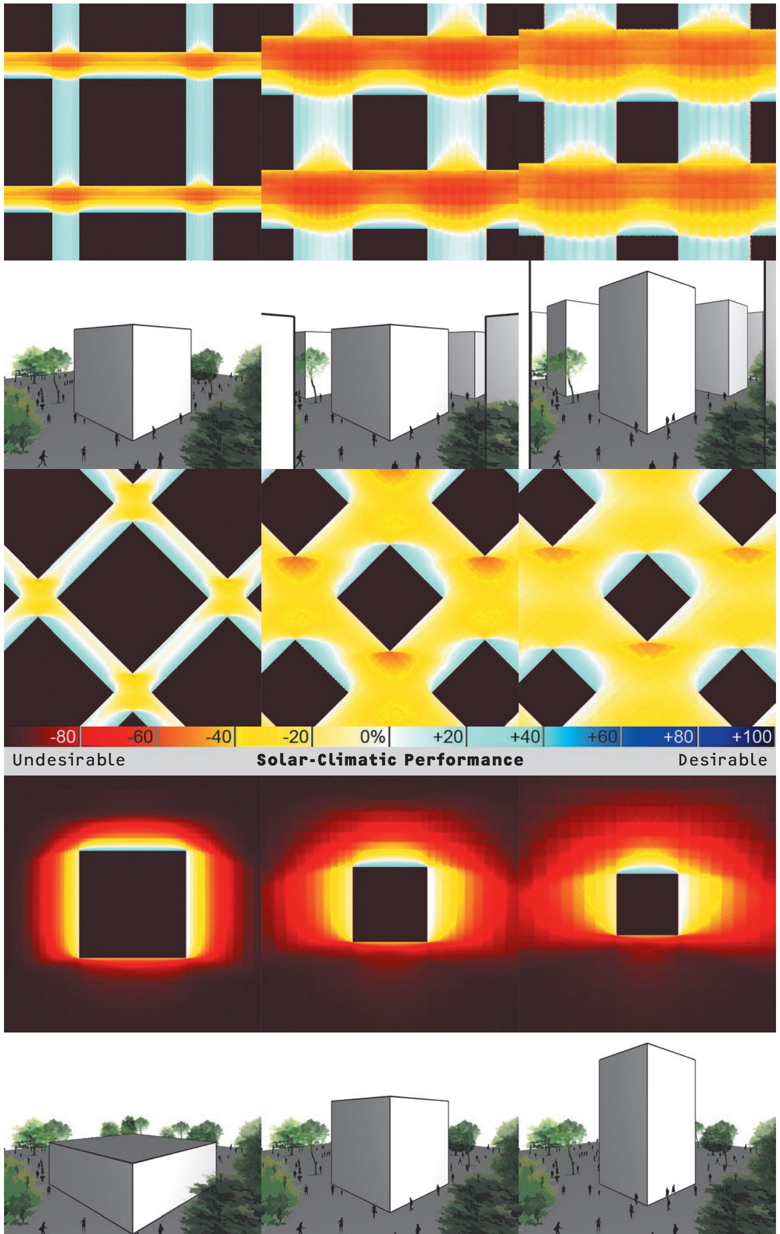


Fig. 240–242: Outdoor/Indoor SOLARCHVISION Analysis—Effects of stretching, orienting and arranging a 700m³ building (floor area: 4x200m²)





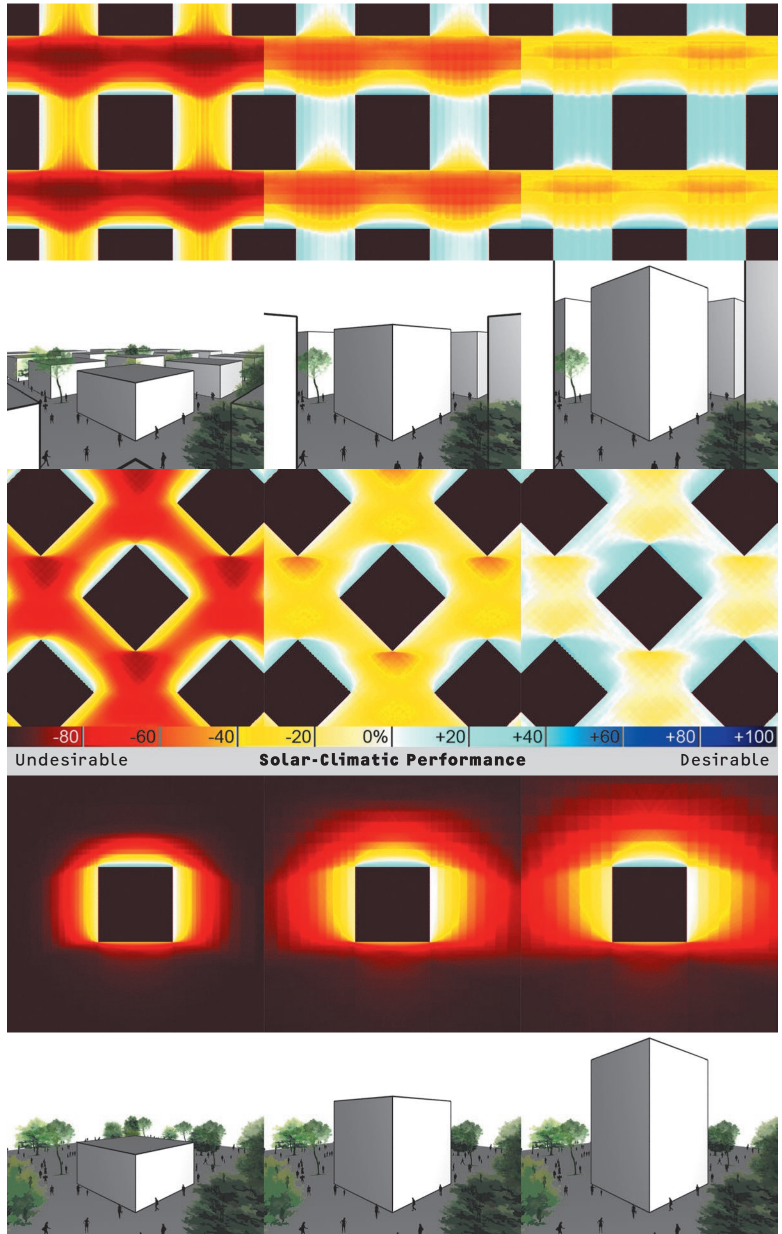
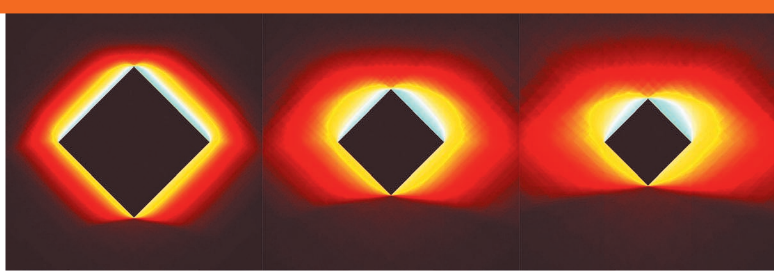
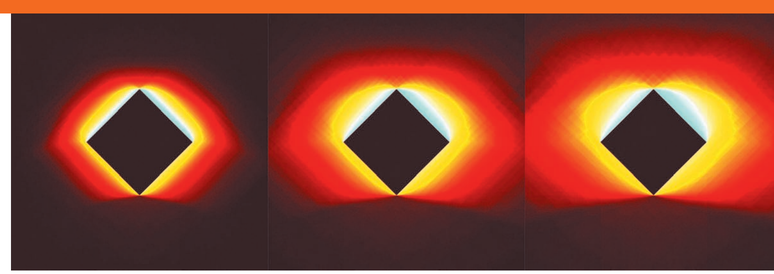


Fig. 243–244: Effect of raising the volume of a 700 m³ building (floor areas: 2 x 400 m², 4 x 200 m², 6 x 133 m²), changing its orientation and array

Fig. 245–246: Effects of increasing the height, changing the orientation and array of building volumes (floor areas: 2 x 200 m², 4 x 200 m², 6 x 200 m²)

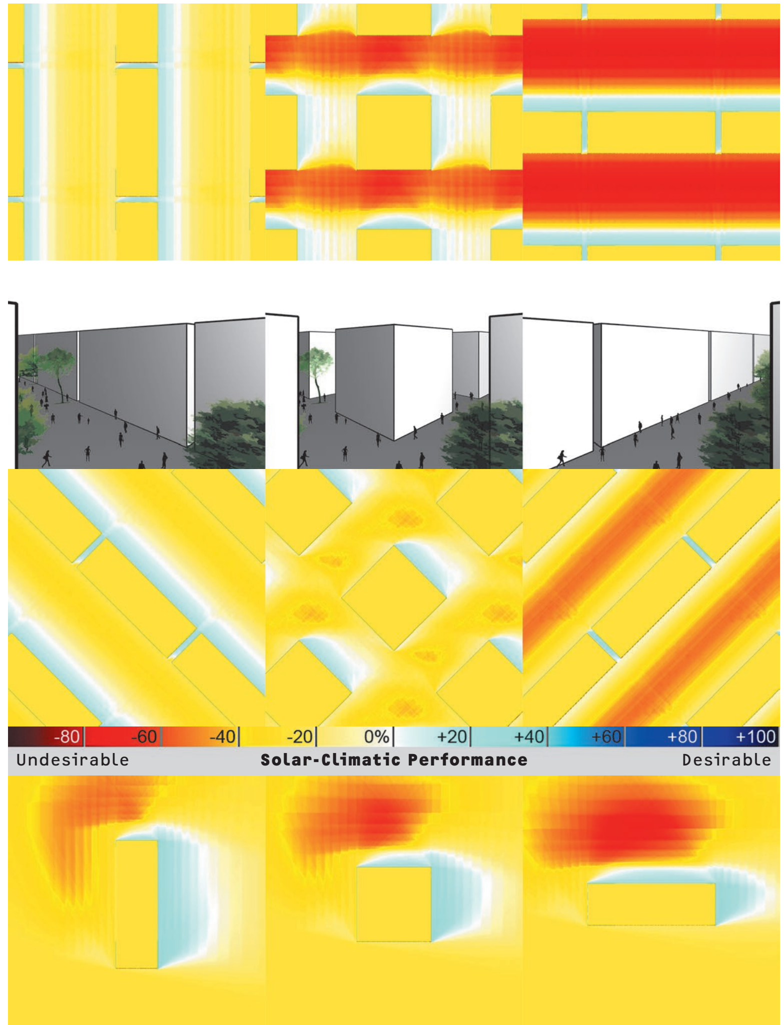




4.2 Design in Dry Climate (Tehran)

The solar-climatic analysis in semi-arid and desert climates, like those in Tehran, Yazd and many other cities of Iran, is very essential. The two main properties of a dry climate are a great amount of solar radiation and great changes in hourly temperature during the day thanks to the clear sky. Similar conditions exist in western cities in the USA, excluding the coastal parts, as well as some central cities in Spain, like Madrid. The north of China, huge central parts of Australia, some cities in Argentina and South Africa also have complex conditions where the sun has remarkably favorable effects in some periods during the year, in addition to totally unfavorable effects at other times. A precise analysis should be done for each of these cities to discover the complex effects of the sun and the climate for the benefit of architectural design and urban planning.

The following analysis for Tehran illustrates the desirable and undesirable areas created inside and outside different alternatives of single and multi-story buildings. The red areas show the locations that are in the shade during most of the cold periods and in the sun during most of the hot periods. The blue areas are the ones with the best conditions during longer periods of time as a result of having either favorable radiation or favorable shade. Besides the passive approach, active strategies, like using solar collectors and PVs which can be installed on roofs or on a range of façades ranging from east to west, help to produce energy for cooling, heating and daylight.



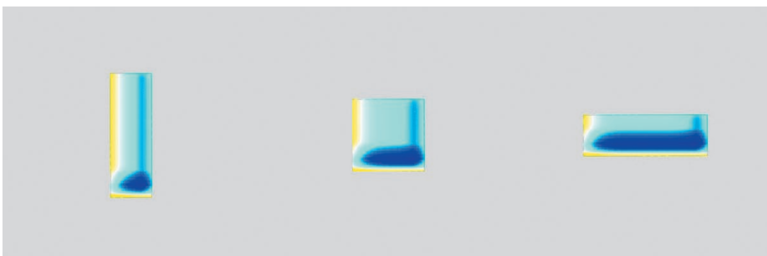
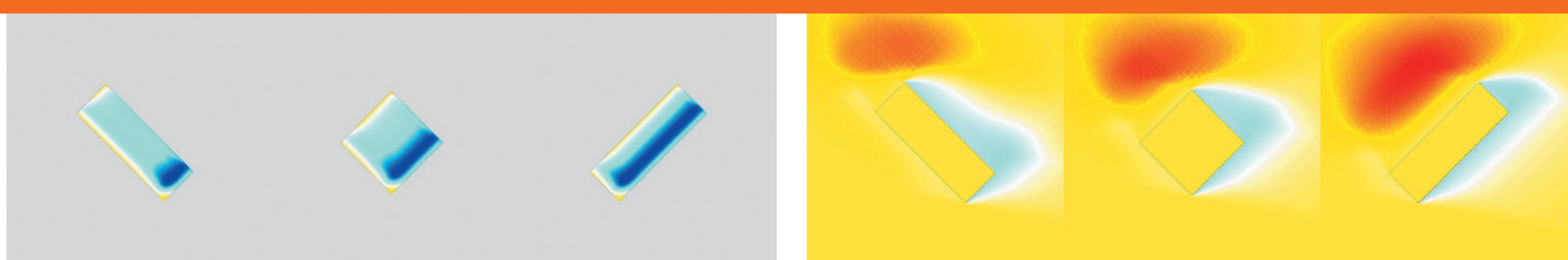
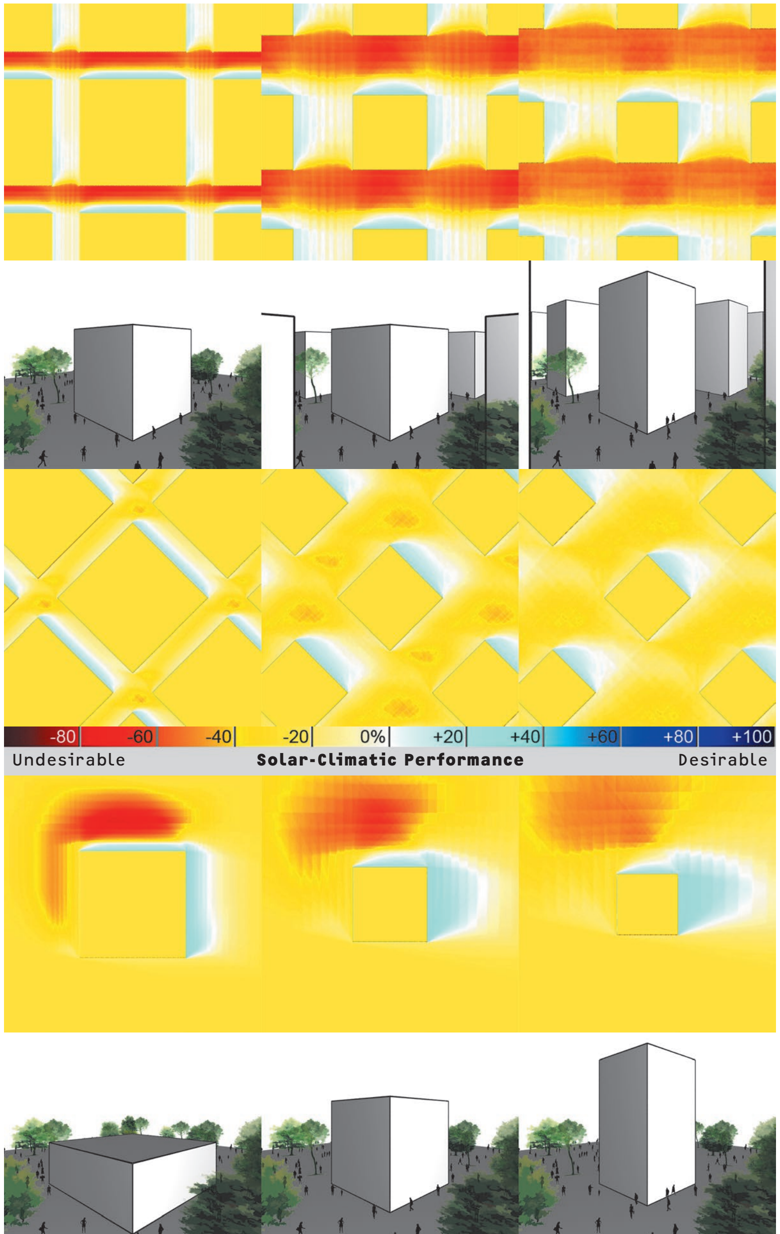


Fig. 247–249: Outdoor/Indoor SOLARCHVISION Analysis—Effects of stretching, orienting and arranging a $700 m^3$ building (floor area: $4 x 200 m^2$)





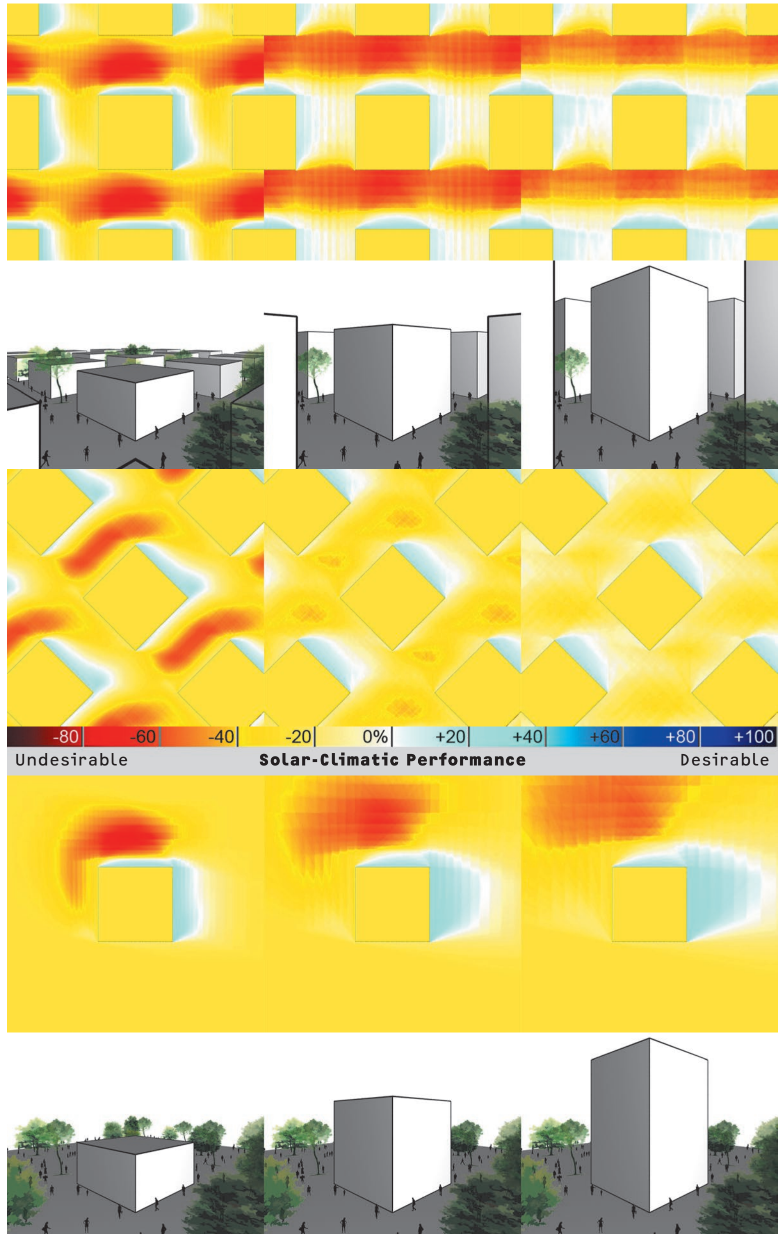
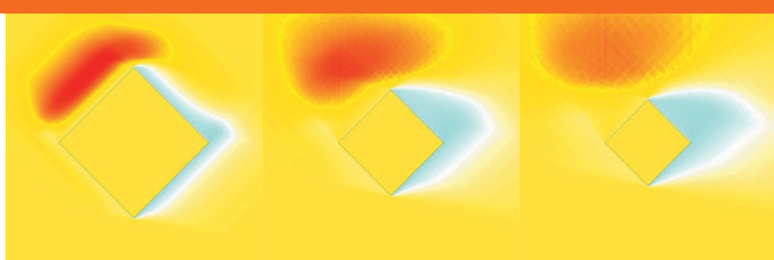
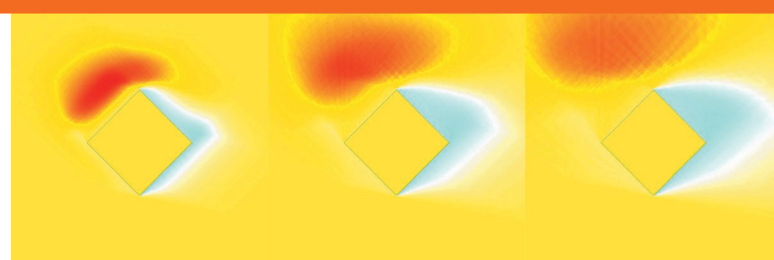


Fig. 250–251: Effects of raising the volume of a 700 m³ building (floor areas: 2 x 400 m², 4 x 200 m², 6 x 133 m²), changing its orientation and array

Fig. 252–253: Effects of increasing the height, changing the orientation and array of building volumes (floor areas: 2 x 200 m², 4 x 200 m², 6 x 200 m²)



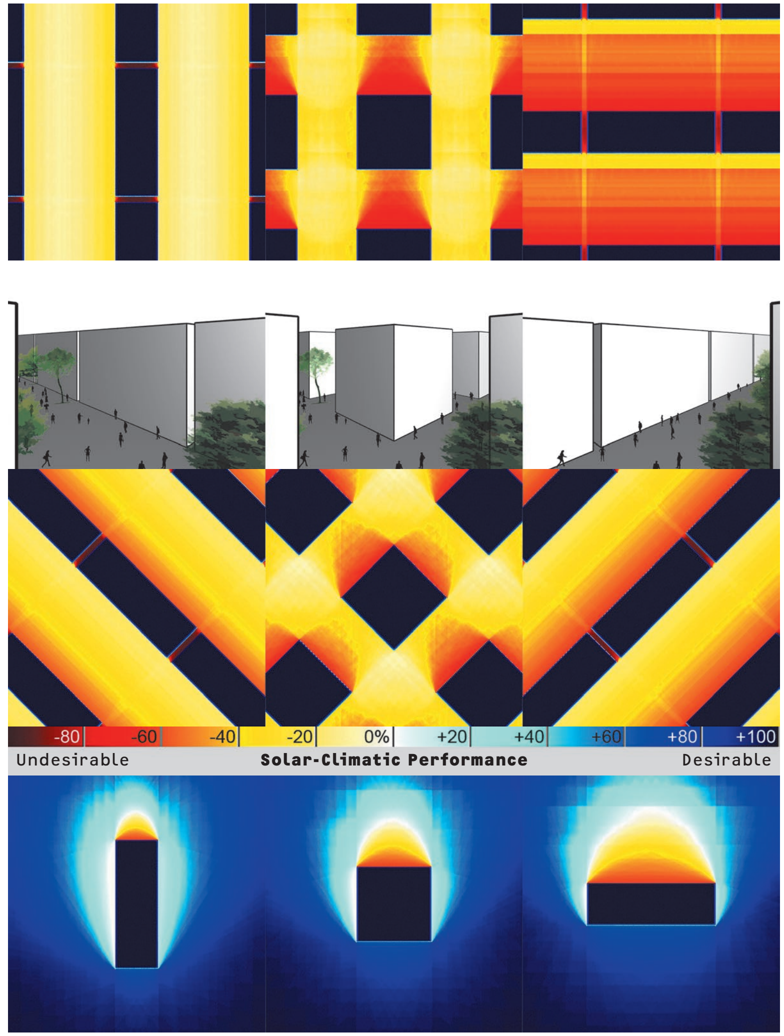


4.3 Design in Cold Climate (Montréal)

Contrary to public belief that the effect of the sun should be studied more carefully in hot climates than in cold climates, in terms of architecture and urban design, the necessity and complexity of such an analysis is high in both cases. As a result of the greater rotation of the sun in the sky at higher latitudes, namely in summer, it is critical to use intelligent shading devices to control the low altitudes of the sun from entering at certain times.

On the other hand, overshadowing can produce serious problems for both the interior and exterior of single and multi-unit buildings during cold periods. Some of these problems are related to the energy efficiency and daylighting performance of the building or its neighborhood. There are also some issues which are related to health, comfort and safety. For instance long-time overshadowing on the north side of a building (here the red areas) can increase the danger for injuries caused by ice. Moreover, these areas generate a different sense of cold for people on the street. In Montréal in winter, for example, almost all sunny mornings are very cold, and standing in the sunshine, for instance at a bus stop, is very different to standing in a place in the shade.

Besides these factors, it is essential to analyze the effects of both existing and new buildings to figure out their effects on each other as well as the open areas in the neighborhood. Tall buildings as well as narrow rows of houses can produce long and intense periods of undesirable shade on other buildings as well as in urban areas.



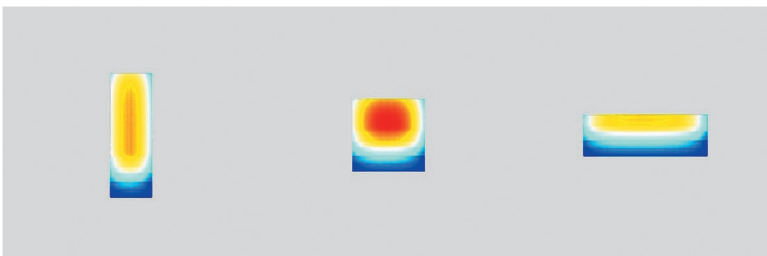
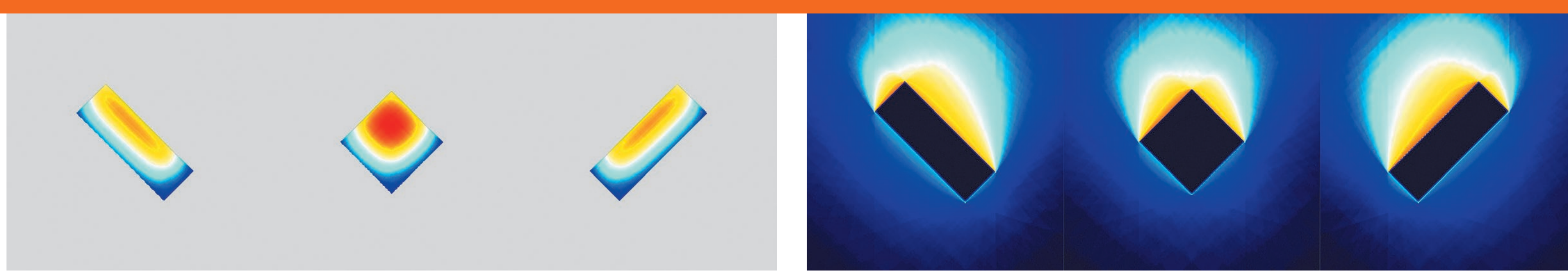
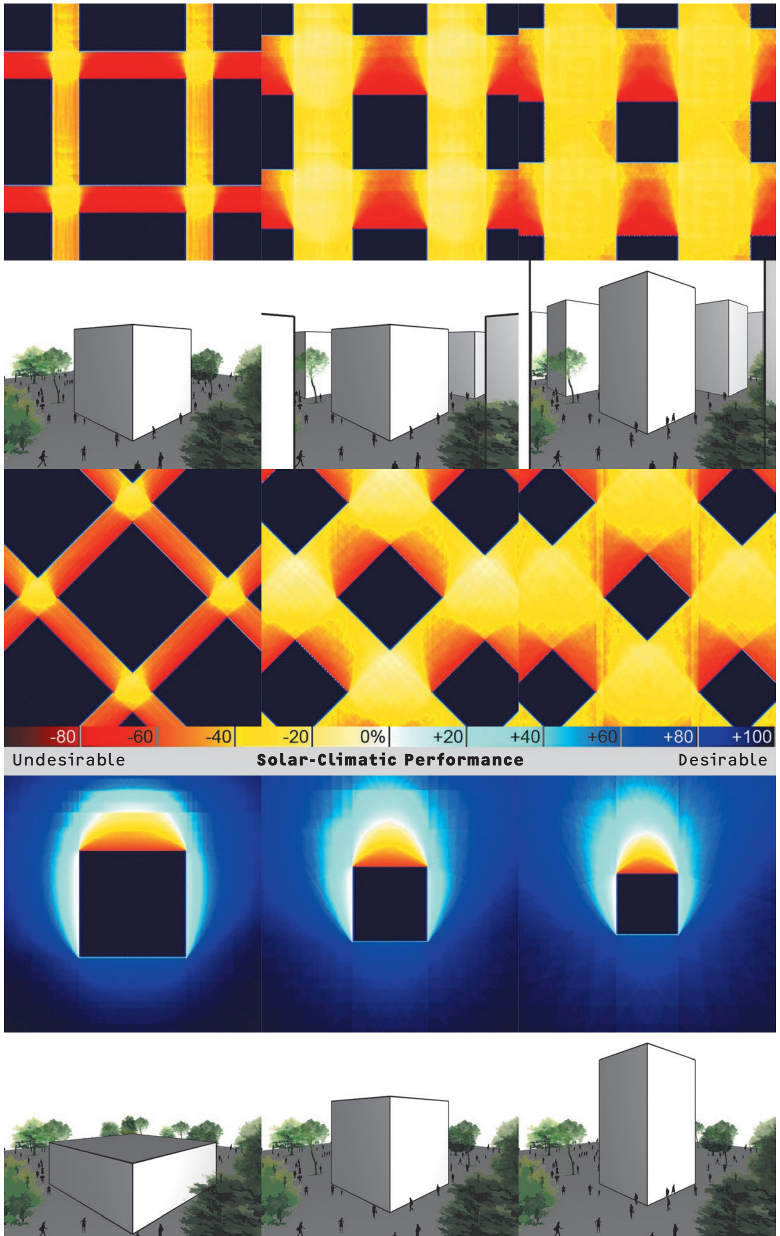


Fig. 254–256: Outdoor/Indoor SOLARCHVISION Analysis—Effects of stretching, orienting and arranging a 700m³ volume (floor area: 4x200m²)





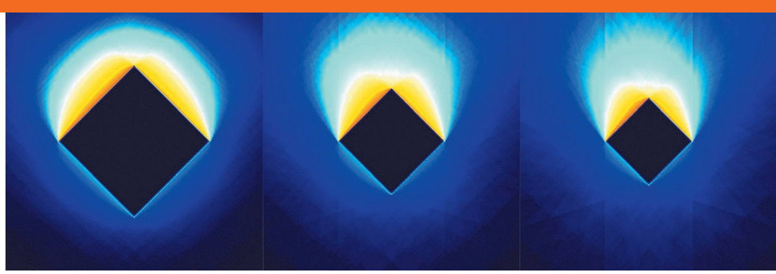
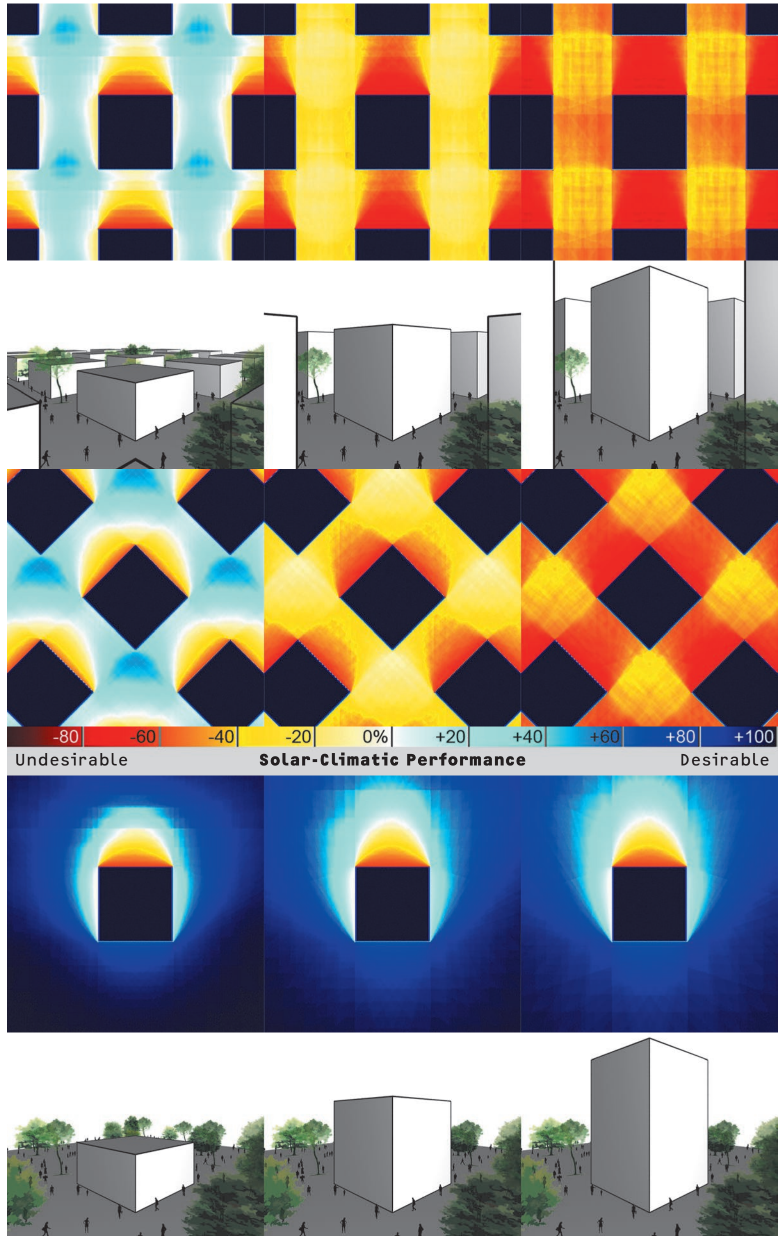


Fig. 257–258: Effects of raising the volume of $700 m^3$ building (floor areas: $2 x 400 m^2$, $4 x 200 m^2$, $6 x 133 m^2$), changing its orientation and array



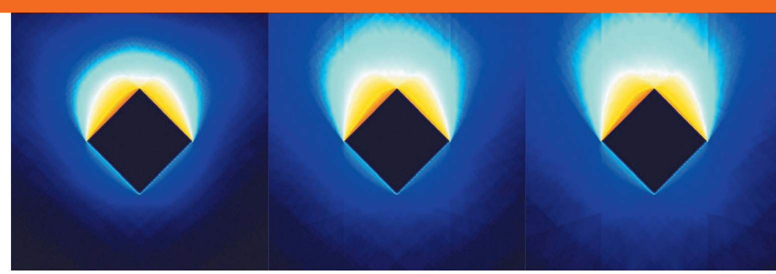


Fig. 259–260: Effects of increasing the height, changing the orientation and array of building volumes (floor areas: $2 x 200 m^2$, $4 x 200 m^2$, $6 x 200 m^2$)

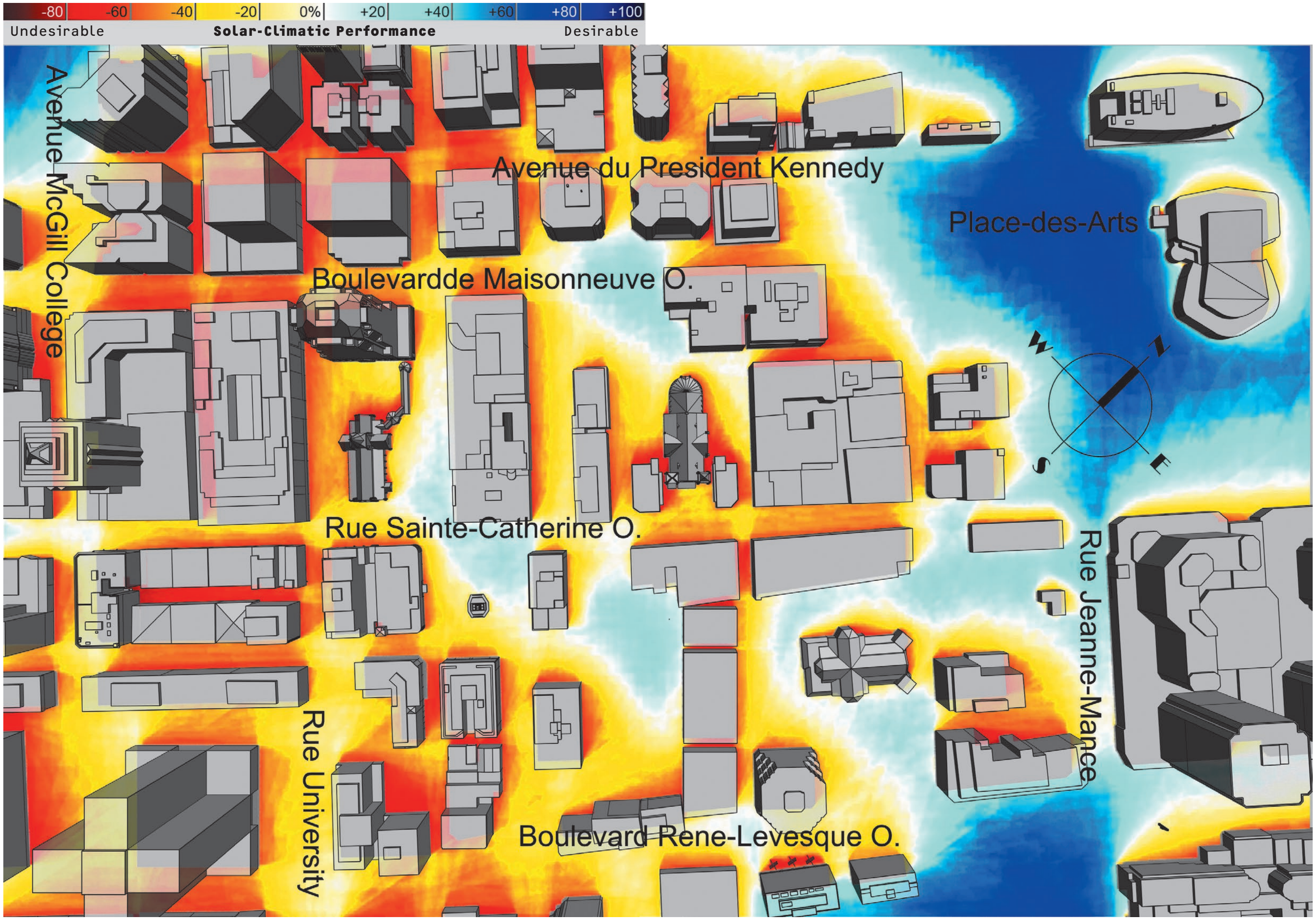


Fig. 261: Annual SOLARCHVISION cycle analysis of Montréal downtown (Google Earth, 2012)

Consequently not only every individual building should be simulated to improve its orientation and form to capture more energy from the sun, but also its negative effects on other structures and areas should be studied and modified. In other words, the major problem here is how to provide pure and unlimited amounts of sun for everyone. The other essential issues, concerning the generation of solar energy on different building surfaces on an urban scale, were discussed in section 2.2.

The SOLARCHVISION analysis presented in Figures 254 to 260 for different building orientations and urban fabrics can be used to figure out the different effects which architects and urban planners should seek to achieve a sound relation between the design and the climatic properties, including the sun. As a result, the application of solar-climatic vision in the early design stage should be integrated in both the process and the product of planning and design around the world.

4.4 Urban Analysis and Modification

In many cases, an urban fabric already exists and a spatial analysis can be performed to discover the areas with high and low solar-climatic performance during an annual cycle or during a more limited period, e.g. the cooling or heating periods, from sunrise to noon, or from noon to sunset.

The SOLARCHVISION analysis presented in Figures 261 and 262 for Montréal downtown shows the solar-climatic performance of different outdoor areas during an annual cycle (Typical Meteorological Year). In consideration of the basic analysis, if the building blocks in the urban fabric of Montréal were oriented true south, there would be more undesirable space, notably between the paths in east-west directions, and due the fact that the direction of the prevailing winds in Montréal is from the west. The current general orientation of Montréal's urban fabric can therefore be considered intelligent in regard of the sun and the climate.

Annual SOLARCHVISION cycle analysis of Montréal downtown On the other hand, to mitigate the undesirable effects of narrow and tall buildings on the urban fabric, it might be advisable to install optimized reflectors on top of the buildings to reflect solar radiation from the sky and the roofs into the urban space.

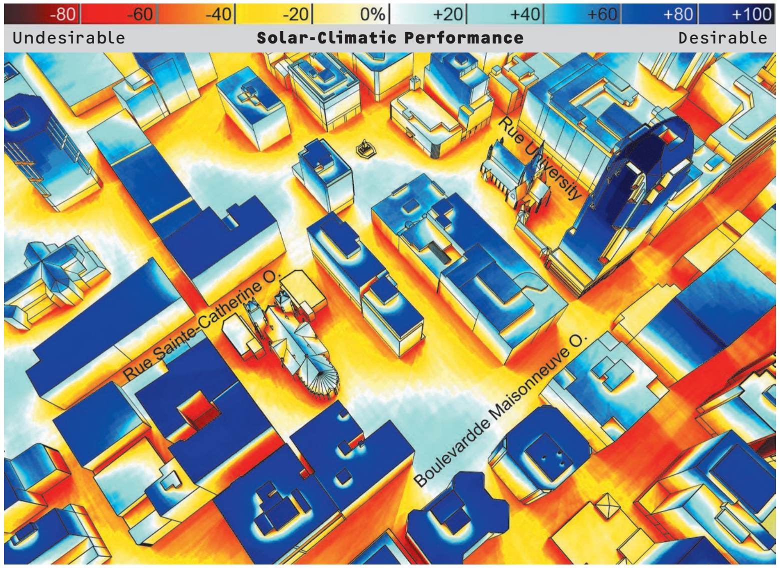


Fig. 262: Annual SOLARCHVISION cycle analysis of Montréal downtown (Google Earth, 2012)

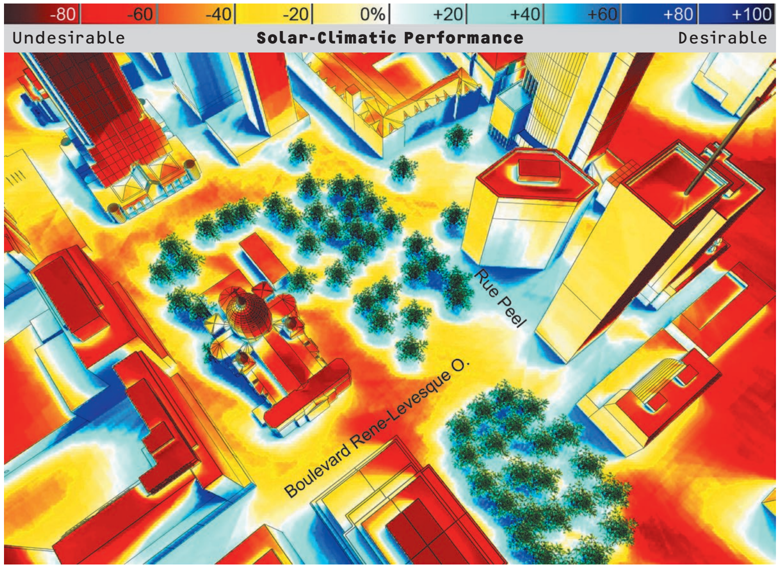
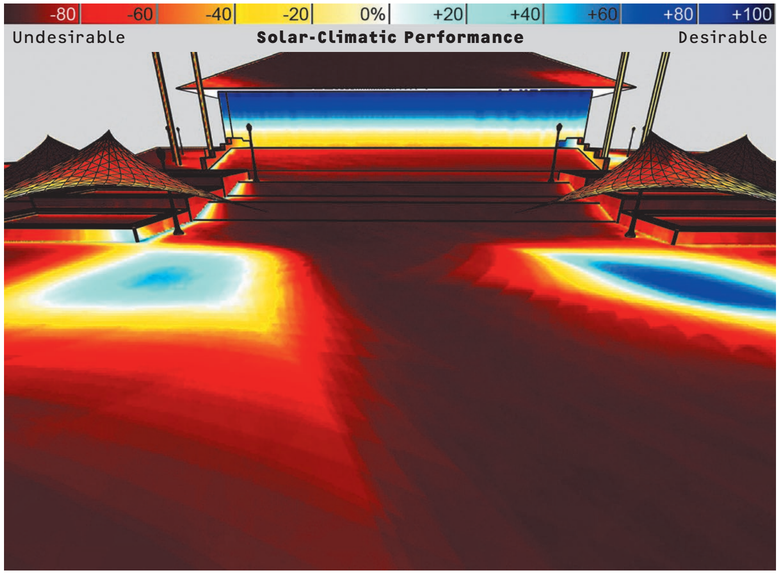


Fig. 263: SOLARCHVISION analysis illustrating the effect of trees in providing comfort during the summer period

As the analysis presented in Figure 263 illustrates, during summer (cooling period), trees can produce desirable shading effects, especially in urban parks.



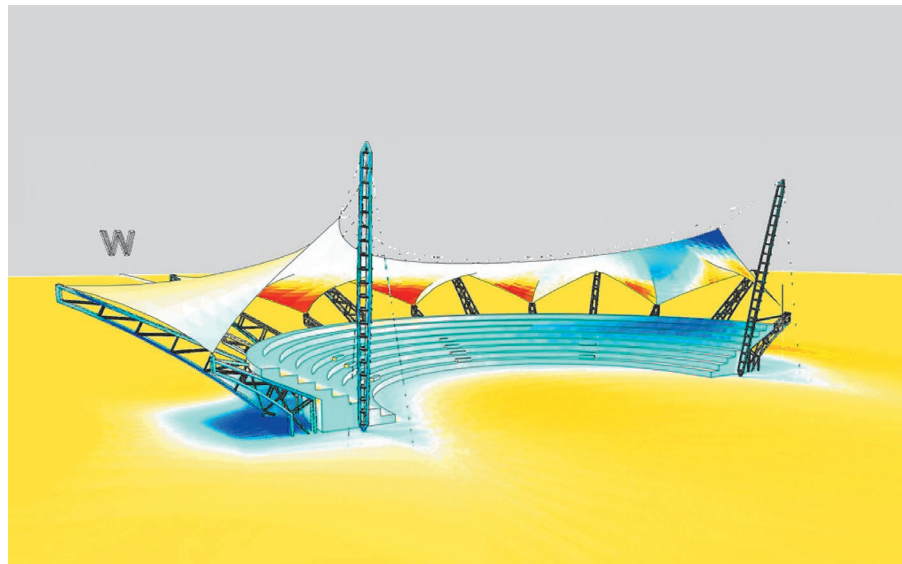


Fig. 264–265: Summer SOLARCHVISION analysis of Mount Royal Chalet and General view of Montréal downtown from Mount Royal Chalet with the proposed tensile shading devices | Fig. 266: "Ab o Atash" amphitheater, Tehran, Iran (Diba and Maffeis, 2009) | Fig. 267: Annual SOLARCHVISION cycle analysis of the complex membrane structure "Ab o Atash" amphitheater (Samimi, 2009)

Mount Royal Chalet is an important location in the city of Montréal. However, the analysis shows low solar-climatic performance of this location in summer (cooling period). In summer, there is almost no place to rest and enjoy the views in comfortable shade having climbed up to reach the place. On the other hand, even on a rainy or snowy day, there is no in-between space in this plaza for better protection. To improve the solar-climatic performance of the place, an alternative has been developed with minimum impact on the views of the city. In summer, the tensile structures protect visitors from undesirable solar radiation during the day. In winter, they also let desirable sun rays reach the people below and protect visitors from the rain and snow, which tends to fall in several months of the year. During the day and at night, attractive views can be enjoyed from different positions of the site and the city. (Samimi, 2013)

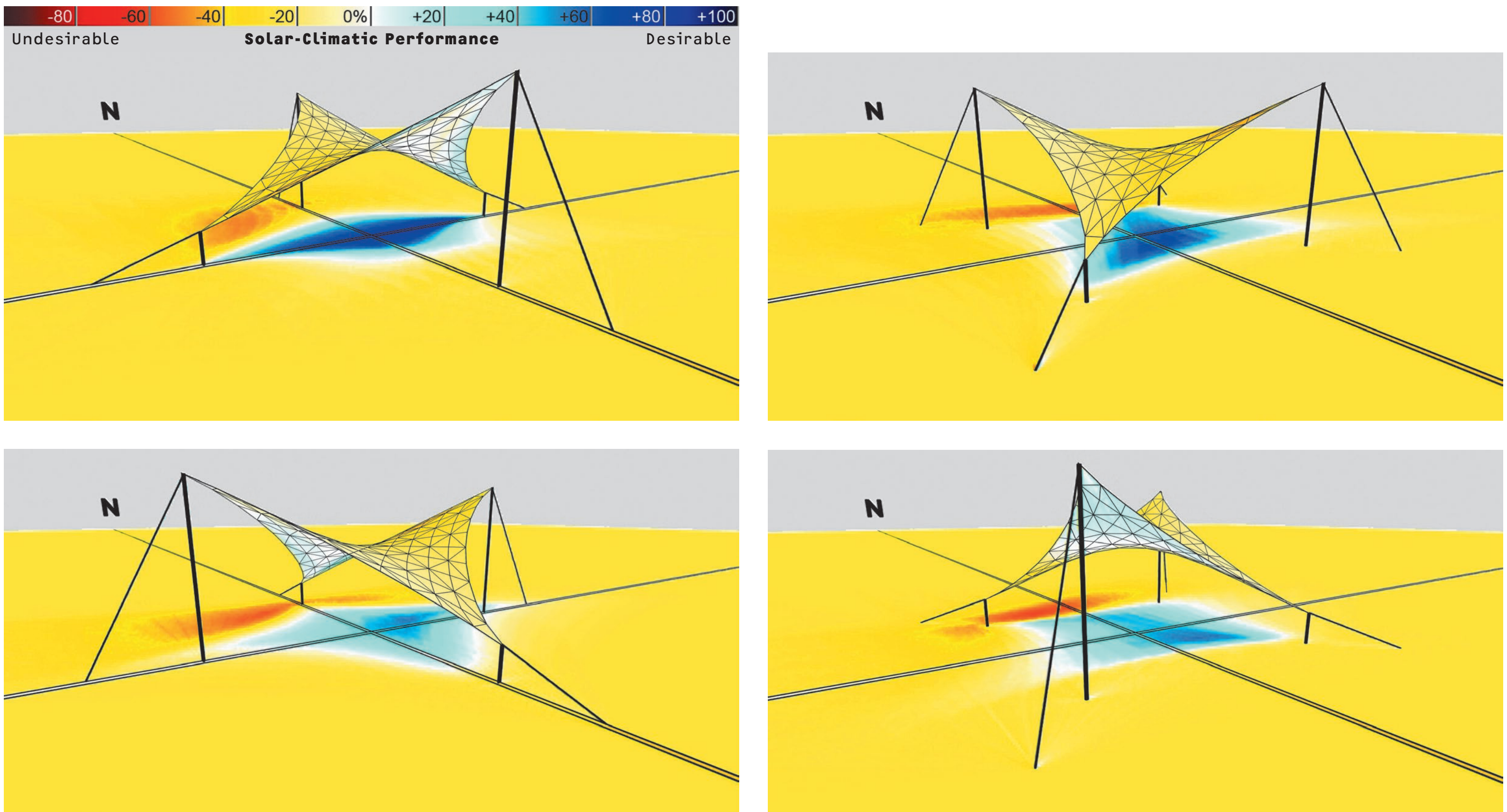
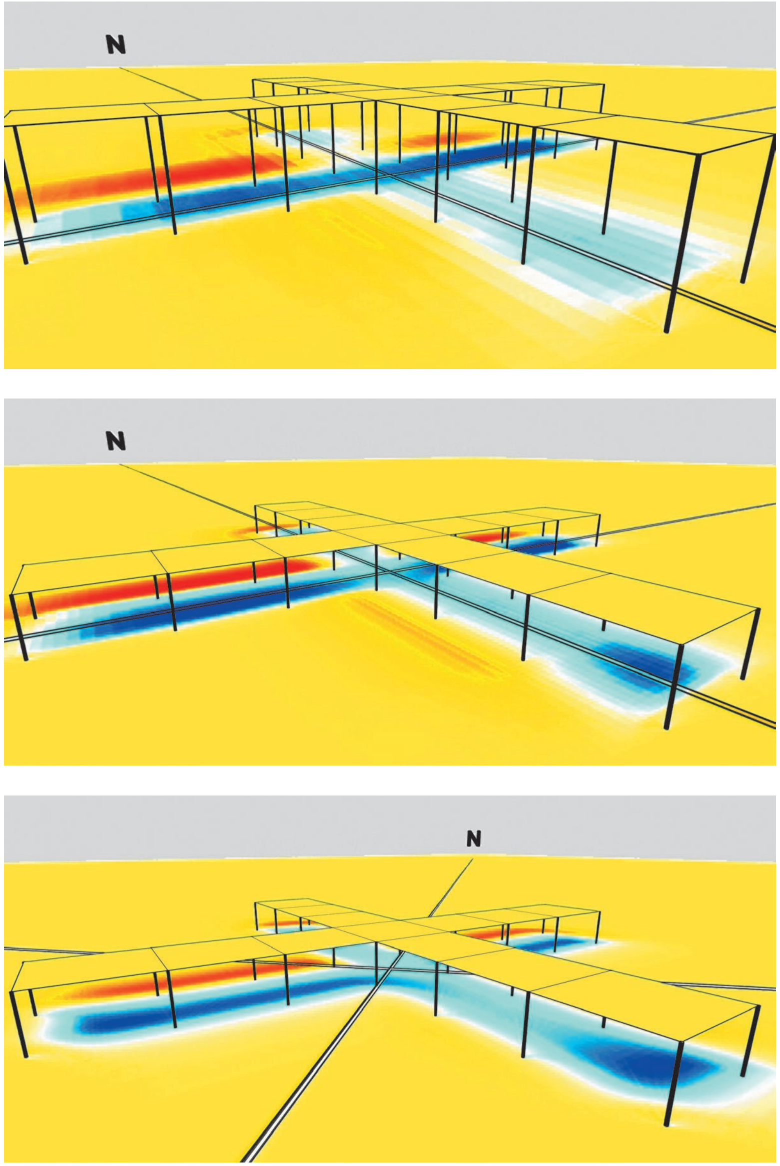


Fig. 268: Annual SOLARCHVISION cycle analysis for the optimization of the orientation of a single tensile structure in Tehran's climate

Outdoor roofs and membrane structures are objects which can improve the solar-climatic performance of urban and outdoor areas. Like trees, the use of these structures should be integrated in the early design process of architectural and urban planning projects. Besides structural optimization, the so-called "form finding" process, the solar-climatic response of these structures can be analyzed by using the SOLARCHVISION program. It is used to optimize the most favorable position, orientation and proportion of the structure. The following studies show the different performance of tensile structures in relation to their orientation, proportion and height. The first comprehensive studies of membrane structures were analyzed by SOLARCHVISION and presented within the IMS lecture series: Institute for Membrane and Shell Technology (*www.ims-institute.org*) in 2009 at Tehran University and in 2010 at Anhalt University of Applied Sciences, Dessau, Germany.



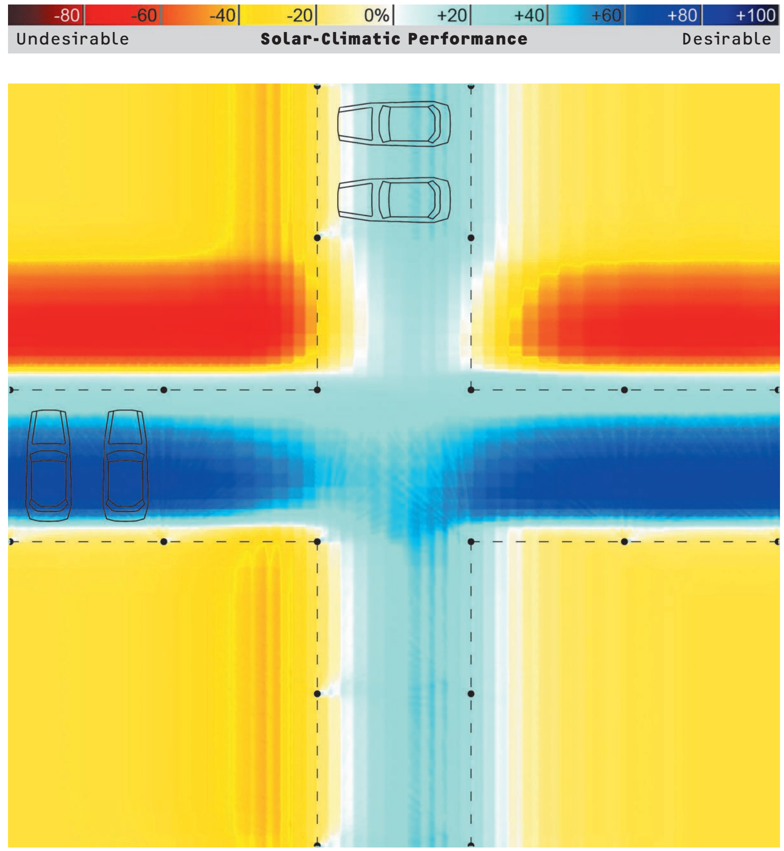


Fig. 269–271: Annual analysis showing the effects of proportion and orientation in Tehran, dimensions: 5 m x 5 m, top: h = 5 m, middle: h = 2½ m, bottom: rotation: 45° (in a S.E.-N.W. and S.W.-N.E. direction).

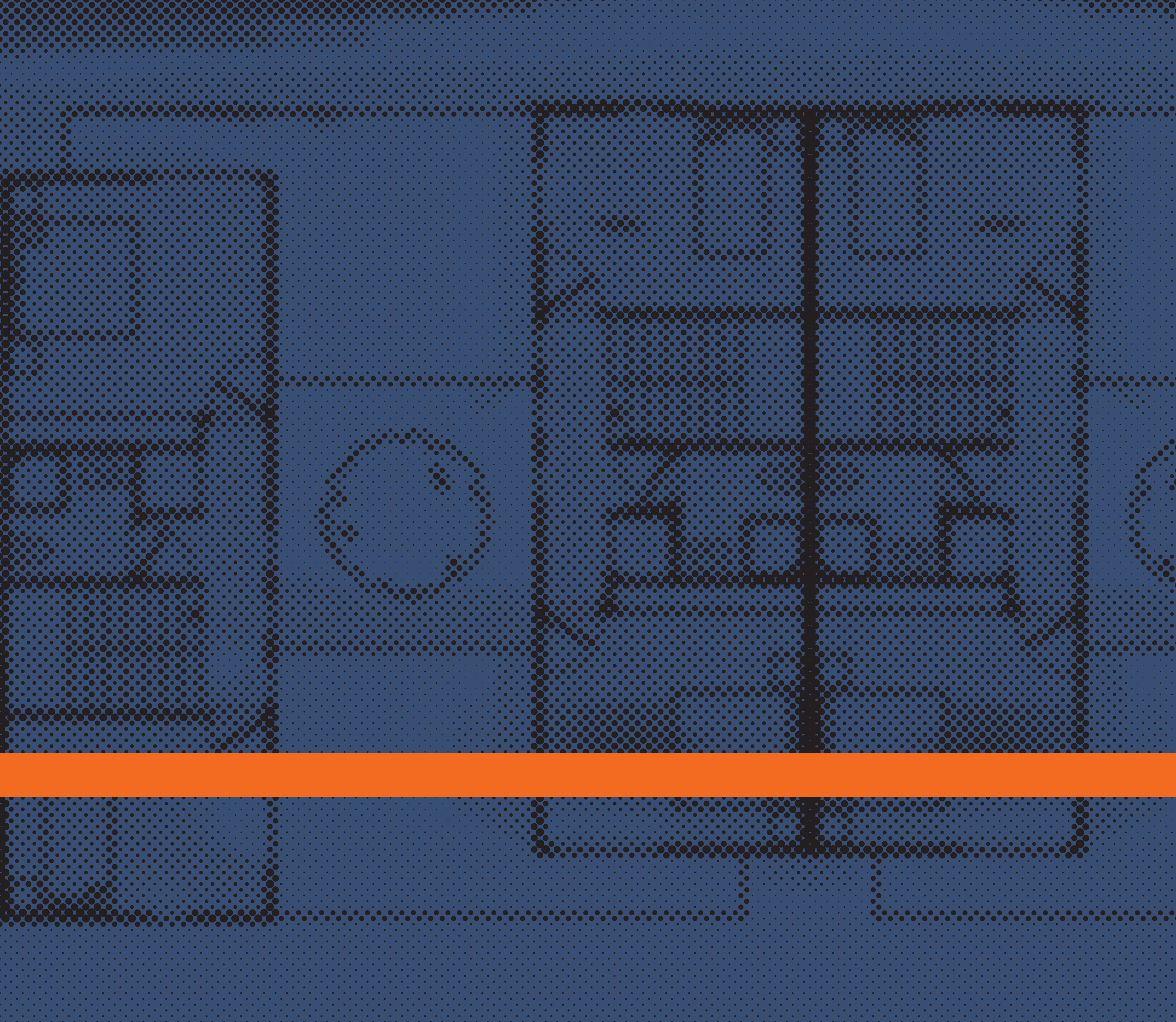
Fig. 272: Annual SOLARCHVISION cycle analysis showing the effects of orientation (east-west and south-north) in Tehran, dimensions: 5 m x 5 m, h = 2½ m

The diagrams presented in Figures 269-272 show the different effects of arranging a modular shading device in different directions in Tehran. The first two diagrams illustrate the analysis for two different proportions. In consideration of this study as well as the analysis presented on the next page for the cities Abu Dhabi and Montréal, the best performance results from an east-west arrangement, simply because this layout blocks out unfavorable radiation in summer and lets the winter sun enter. As a result, this orientation and layout for parking is considered best to increase the provision of more comfortable areas in the shade. These analyses can help designers to create better conditions by choosing more appropriate proportions and orientations in laying out structures on the site. For instance, in regard to the analysis of Abu Dhabi, better conditions are created by applying short and wide proportions in hot climates; whereas in cold climates, like Montréal, long and narrow ones are more suitable.

1 different color palettes are used to show different amounts of solar energy on each surface

2 middle left: annual total positive and negative effects, middle right: annual ratio between the positive and negative effects, below: advanced SOLARCHVISION passive model resulting from the multiplication of two layers

IV
Solar-Climatic Vision in Design and Planning



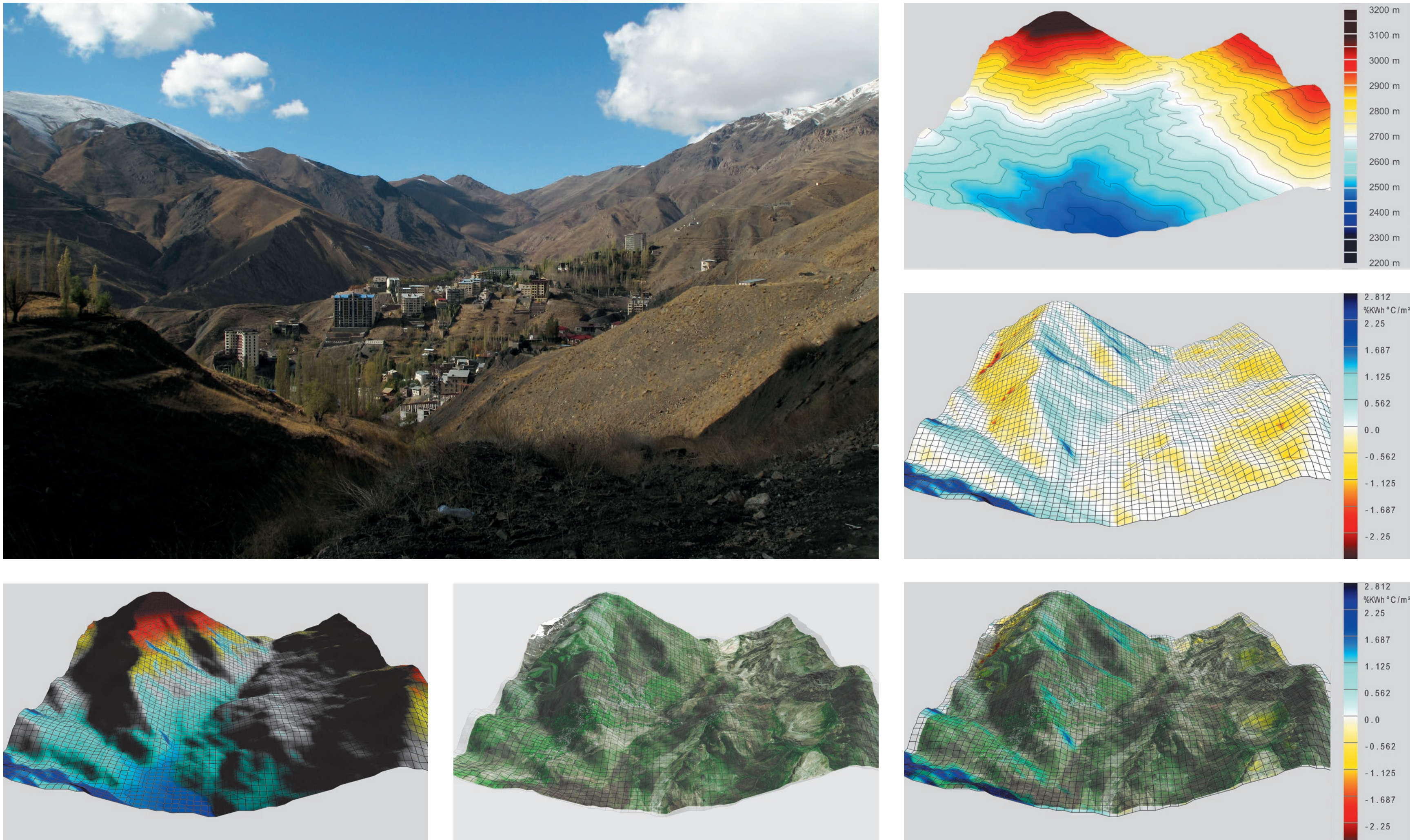


Fig. 273: Application of SOLARCHVISION analysis to determine favorable places on a major scale site with varied sloped surfaces (with overlay of other GIS layers: e.g. elevation, accessibility), case study: 370 hectares land in Shemshak, Iran, in collaboration with R.M.M. architects (photo: Reza Mohammadzadeh)

Architectural design and urban planning have remarkable effects on human life as well as life on the earth. In addition to a sound relation between the building's skin, the urban fabric, the sun and the climate in creating a sustainable built environment, there are other aspects which should also be considered. An understanding for the complexity of the design process is essential from the first step onwards. Recognition of different layers as well as their interaction can therefore help to develop each parameter throughout the design process. On the other hand, simplicity of the product is another factor which should be appreciated by both the designer and the client within this process; however, a proper simple solution cannot be found without a comprehensive integration of a variety of quantitative and qualitative parameters. Meanwhile, such a simple response is complex in another respect. Failure to find an optimized solution in each case results in greater investments in other dimensions,

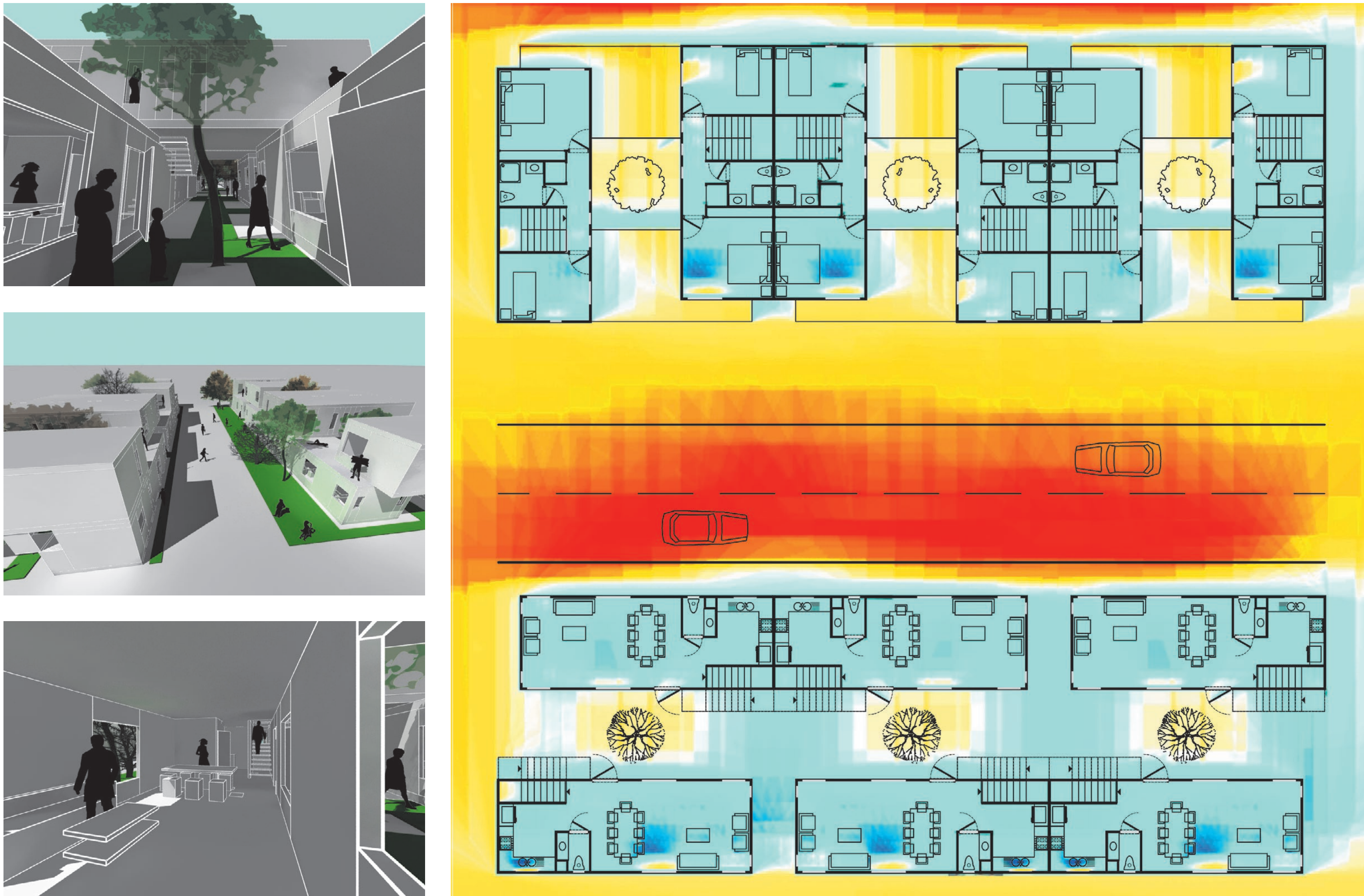


Fig. 274: L-units complex (Samimi, 2011)

such as structural, environmental and energy-efficiency measures. For instance, the ignorance of the role of the skin as a result of the availability and inexpensiveness of fossil fuels in the past decade has affected architectural design and thus the construction industry in many cities around the world. As is discussed in regard of the skin, challenges of form generation and form finding, as well as form improvement in the architectural design and urban planning, are important issues to combat local and global challenges. On the other hand, buildings and urban spaces need structures and infrastructures too, and most importantly, they have a remarkable impact on the environment. This means that, despite the fashion of time, the building's boundaries must be developed in connection with not only the external parameters but also the internal and intermediate ones. In many cases, the modification of existing buildings and technologies should be considered rather than proposing avant garde-looking or regular concepts which might impose over-designed structures and HVAC systems. In a word, the intention should be to determine what can be inherited and what must be changed.

In the R&D project (Figure 274) the main objective is to shape a new generation of residential units to replace Iran's ordinary building mass (occupying 2/3 of the lot on the northern side). Instead of developing 6 × 8 m volumes on 6 × 12 m plots, this combination of units creates internal courtyards, as well as either simple or complex urban fabric. Each residential unit consists of two 4 × 11 m lower and upper parts which are basically rotated on top of each other. Consequently, the structure maximizes the perspective, daylight and natural ventilation opportunities for each unit, as well as the perception of living in a bigger house. By locating a similar unit on the other side of each 12 × 12 m plot, a courtyard is developed at ground floor level, which can be connected to neighboring courtyards to create a pedestrian entry alley. This combination also produces a 4 × 4 m terrace for each individual unit on the first floor. A standard layout is presented, analyzed and optimized for the climate of Tehran (e.g. the east-west road is shifted slightly to the south to maximize the areas for more comfort in the north for pedestrians). By applying all necessary changes, a similar concept can be also developed and optimized for other orientations, but also for other climates (e.g. hot and humid regions).

However, most concerns regarding climatic and energy-efficient architecture are about how to deal with extreme and average conditions; careful attention should be paid to other conditions during the year namely the favorable conditions (as plotted in green in the Degree of Need to Shade/Shine diagrams of each city, see Figures 64–68). For instance, it is probable that a building offers perfectly comfortable conditions inside during the cold days of winter as well as the hot days of summer thanks to HVAC systems. However, the building may not function properly during times when the difference between the outside temperature and the comfort zone is at a minimum. Undefined and changing situations of weather during these periods (spring and autumn in general), as well as extreme fluctuations in daily temperatures, which are very common in dry climates, can also be confusing, particularly when both, the heating and cooling system, should be turned on and off during certain times of each day. In addition to technical solutions and in consideration of weather forecast scenarios using smart systems, architectural solutions can also help to improve the situation in another way (e.g. maximizing the possibility of natural ventilation).

1 Looking from the Sun

As is described in the section titled "Past and future challenges", to achieve an integrated design, all aspects and in particular the relation of the architectural form with the sun should be taken to heart and implemented conscientiously by the architect or planner.

However, there are also a number of computational tools available or under development to evaluate the interaction between buildings and the climate under varied effects of the sun. Each tool has its advantages and disadvantages. For example: although it is important to control shading during different hours of the day and in different months, this process can take a lot of time when using 3D-modeling and simulation. In a similar way, there are more complex situations with regard to studying reflective surfaces. To restore this time within the design process, more attention should be paid to architectural modifications in relation to the sun, rather than shading visualizations. Another practical method is worth mentioning, which can be presented briefly in the sentence: "However, it is not advisable to look towards the sun; to develop solar architecture and urban planning, it is always better to look at matters from the perspective of the sun." (Samimi, 2007)

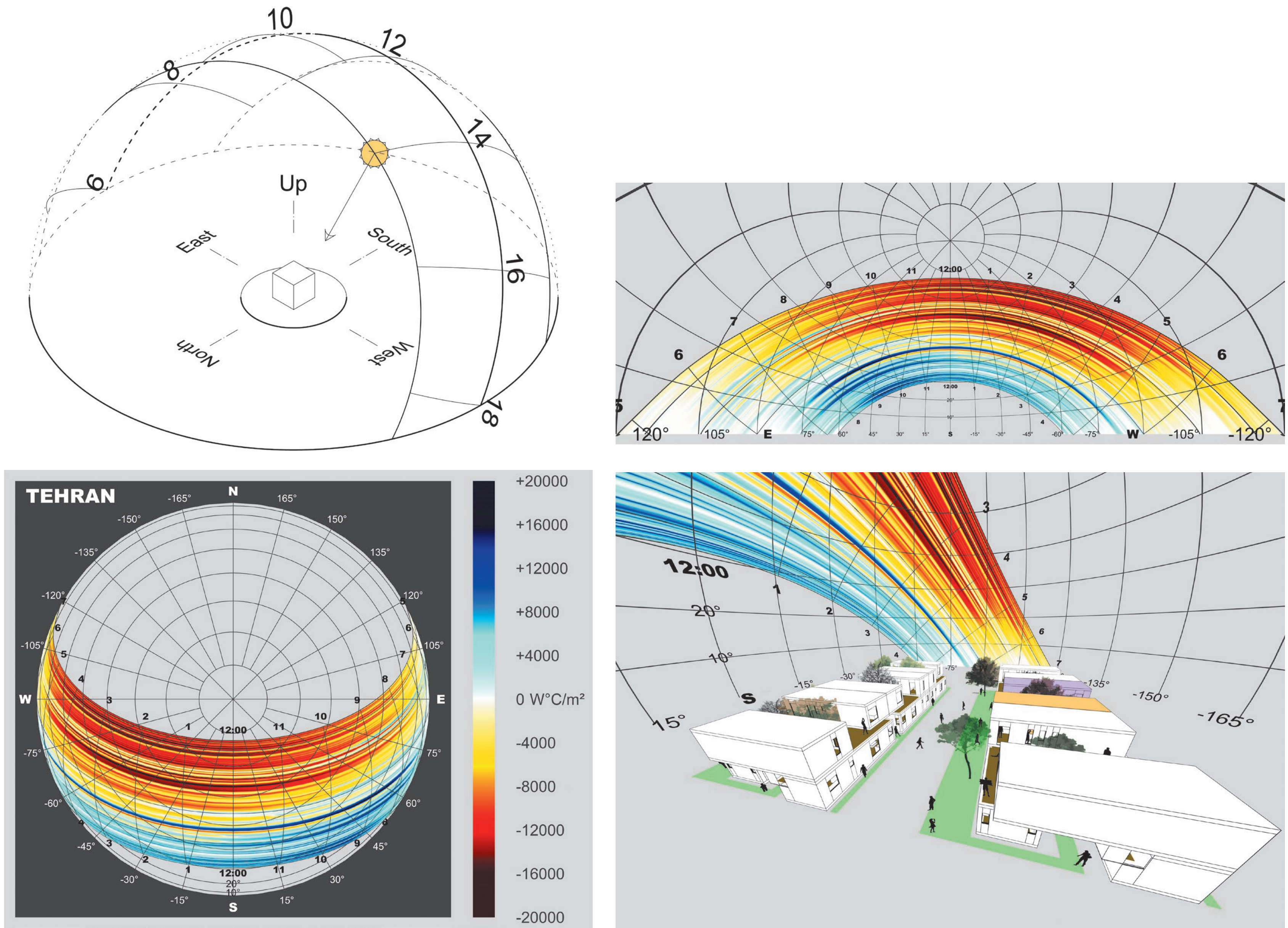


Fig. 275–278: Basic diagrams to perform a solar-climatic vision in architectural design and urban planning, L-unit complex, Tehran

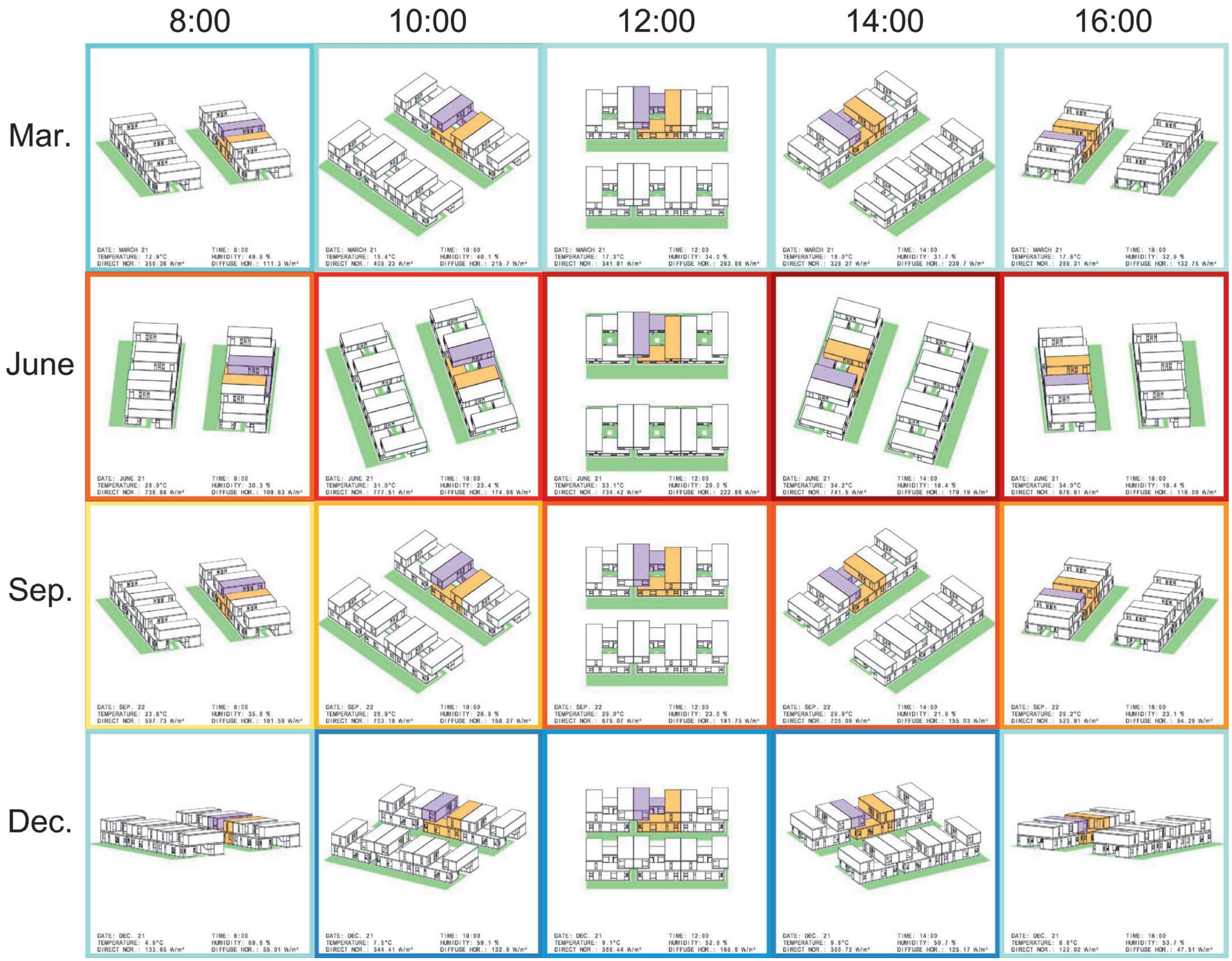


Fig. 279: Perspectives from the sun in different hours and months and the average positive and negative solar effects at each moment, Tehran

Figure 279 presents a variety of perspectives showing the effects of the sun on each building and urban area at different hours and in different months. Similar to the previous diagrams in this book, the palette from blue to red illustrates the positive and negative solar effects at the time corresponding to each view. Such studies are performed to find out which surface is more exposed to the sun during the day and the year, as well as in critical times. They are also useful to discover whether the designated shading devices and reflectors work correctly or not. Meanwhile, for each perspective, the reflections and necessary shading devices can simply be sketched in by the designer.

Figure 280 illustrates the perspectives from the sun in probably the most extreme climatic conditions of Tehran. As is described before, it is always necessary to pay attention to the fact that the longest and the shortest days of the year (21 June and 21 December) are not automatically those

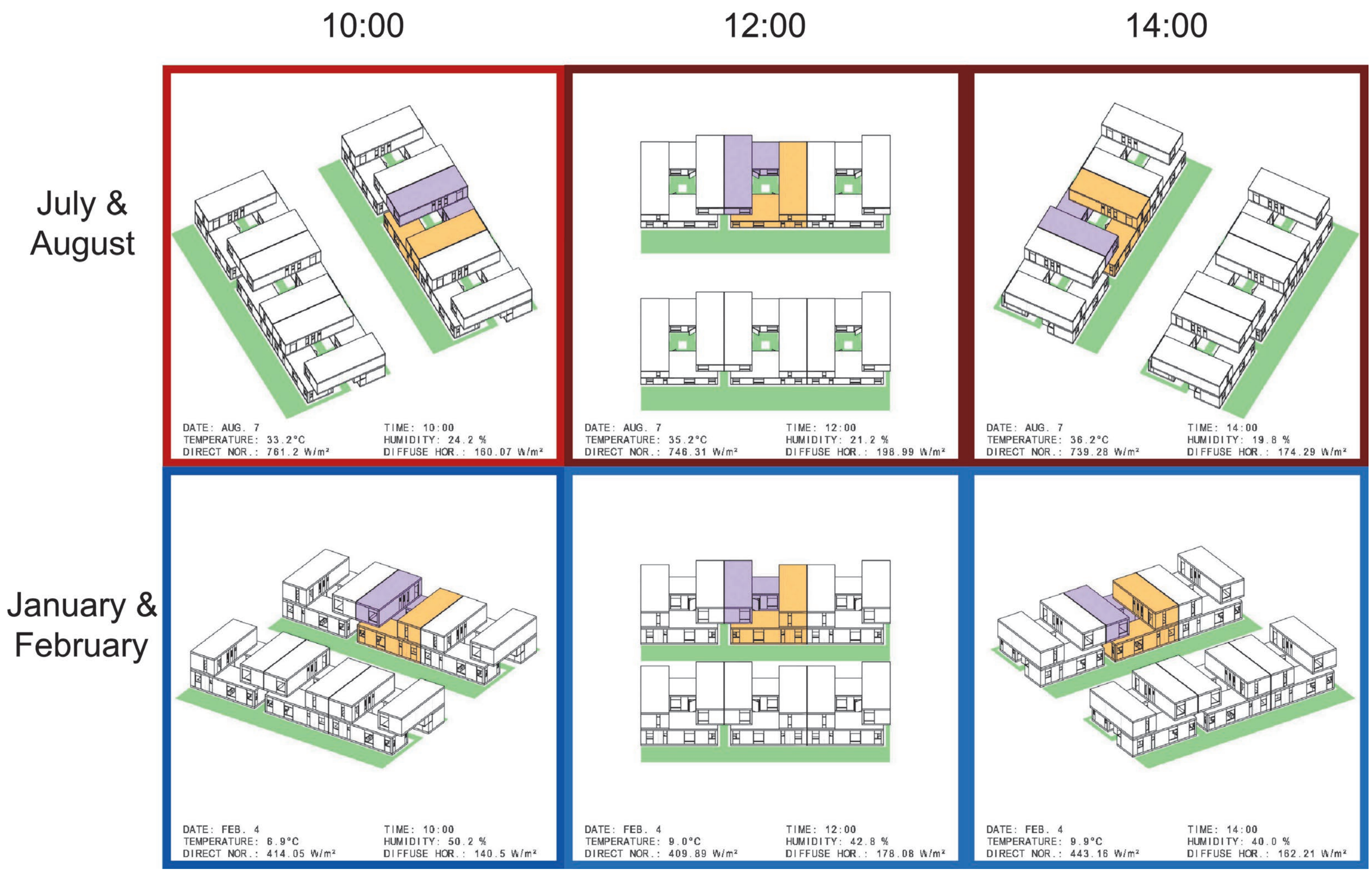
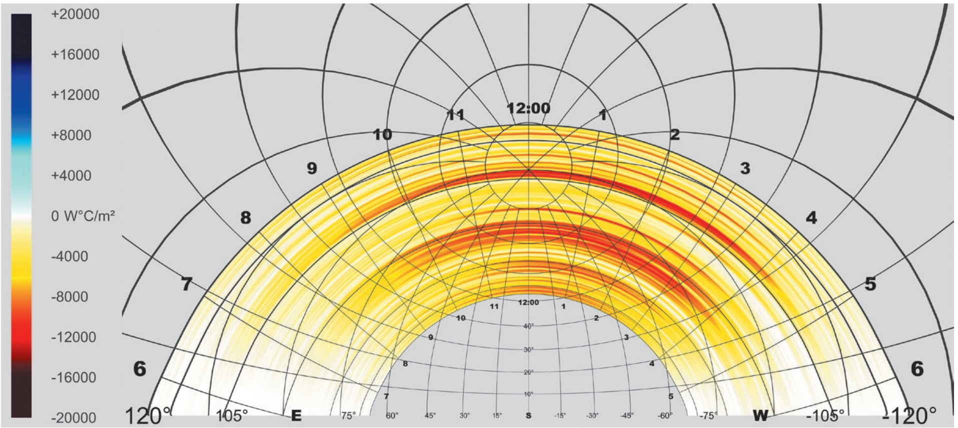


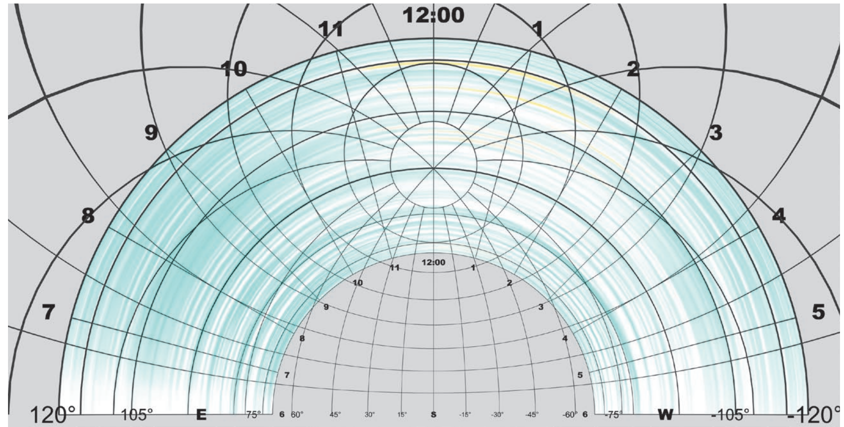
Fig. 280: Perspectives from the sun in extreme climatic conditions, Tehran

with the most extreme weather conditions. In terms of shading in summer, for Tehran this means that it is more important to study August than June. By using hourly summer perspectives, the incidence of the sun in each orientation (e.g. south and west) is easy to understand and can be used for planning the most suitable shading devices in each facade. In a similar way, using winter perspectives, the incidence of the sun on each surface (e.g. south and roof), as well as the urban areas as a whole, can be applied to control undesirable overshadowing of structural volumes and their shading devices, as well as the planning of reflective surfaces (e.g. pools).

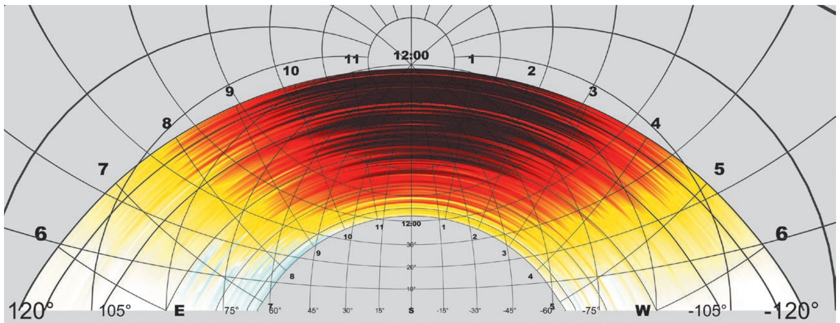
To sum up this part, a number of basic graphs are presented in Figures 281–286. Similar to the sun path graphs presented in the first chapter, these graphs can be used to discover the most essential times and the position of the sun at which one should study the effects on buildings as well as open spaces. (In contrast to the previous graphs and in order to present



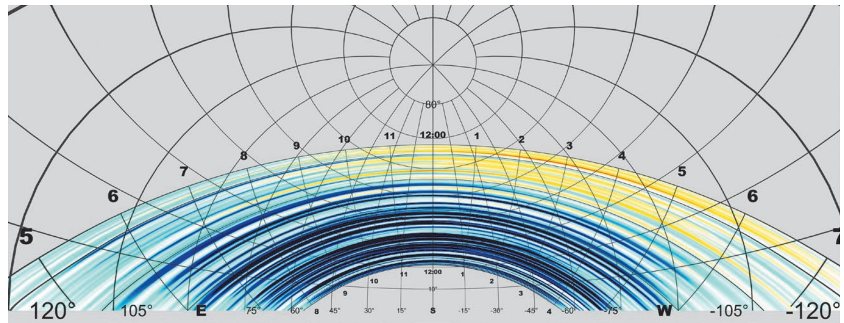
Bangkok, Thailand, latitude: 14N, elevation: 10 m



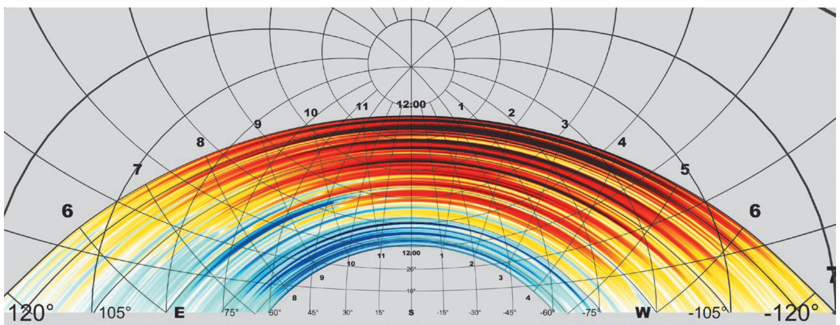
Quito, Ecuador, latitude: 0, elevation: 2,800 m



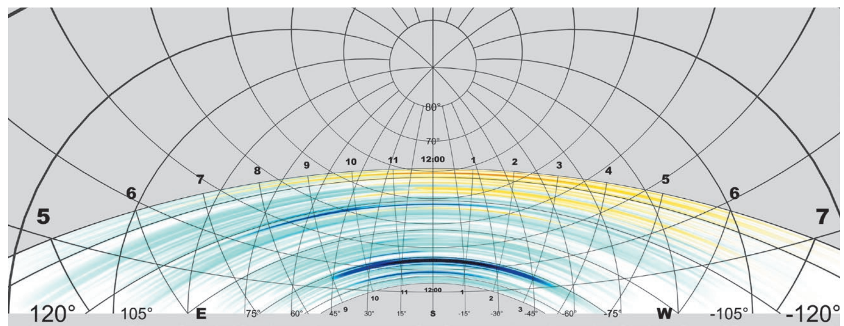
Abu Dhabi, UAE, latitude: 24N, elevation: 25 m



Montréal, Canada, latitude: 45N, elevation: 40 m



Las Vegas, USA, latitude: 36N, elevation: 650 m



Berlin, Germany, latitude: 52N, elevation: 50 m

Fig. 281–286: SOLARCHVISION plots of hourly positive and negative effects of direct solar radiation in vertical stereographic projection (U.S. Department of Energy TMY files)

one annual diagram, instead of two half-annual cycle diagrams, the higher of the two values is selected and displayed).

Today new technologies are responsible for the introduction of modern products that make use of the pure and unlimited energy of the sun for people all over the world; unfortunately, not enough attention is being paid in most developing countries to the proper use and vast benefits of renewable energies. For instance, by taking a look at the great differences between the amount of solar radiation in cities in Germany and Middle East countries, a reverse relationship between the potential and utilization of solar energy can be discovered! Moreover, every year many new projects are initiated in the Middle East with no proper concern with regard to the time or expenditure of their proper design, especially in relation to the sun and the environment. Taking these countries as an example where an abundance of solar radiation is available in the shadow of the considerable yet finite resources of oil and gas: *The richer we are in resources, the poorer we act towards the environment?* (Samimi et al. 2011)

As the result of recent research performed in the context of Task 41 of the International Energy Agency on *Building Integration of Solar Thermal and Photovoltaics—Barriers, Needs and Strategies*, a similar lack of attention to solar energy in new buildings is observed in some developed countries as well. A survey published by the experts of 14 developed countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Italy, Norway, Portugal, Spain, South Korea, Sweden and Switzerland) highlighted, *"the results showed that, despite an overwhelming interest in solar technologies and active solar design solutions, with 80% ranking it as important, only very few are applying it in their current architectural practice on a regular basis."* (Farkas and Horvat, 2012)

While in Germany no one voted *"unimportant"* for the question *"Importance of solar energy in architecture"*, in Norway, only 45% voted it as important. *"Canada, Norway and Sweden showed a similar low use of active systems." "The reasons for such responses may be based on the inexpensive electricity and natural gas in Canada and, possibly, a general belief that Sweden and Norway may not receive enough solar energy for an efficient use."* (Farkas and Horvat, 2012) None of the interviewed experts from Germany and Austria voted "insufficient solar radiation" as a hindrance for the widespread use of photovoltaics and solar thermal collectors (Farkas and Horvat, 2012).

In consideration of the fact that "existing buildings account for over 40% of the world's total primary energy use and 24% of greenhouse gas emissions" (Wall et al., 2008), everybody is obliged to make effective changes not only to reduce their energy payments but also to combat local and global problems, such as heat island effect, pollution, and global warming. In addition to the role of architects, urban planners and other engineers in creating and modifying comfortable and energy-efficient buildings and cities by advancing their designs, using better concepts and materials, the role of clients, builders, users and the whole industry should also be studied and improved in each country with all their characteristics. In summary, an overview on current statistics of world energy should include the current status. But the question is can we speed up the changes in our minds as well as these statistics to meet the rapid orbit speed of the earth, as is described in the beginning, around itself and around the sun?

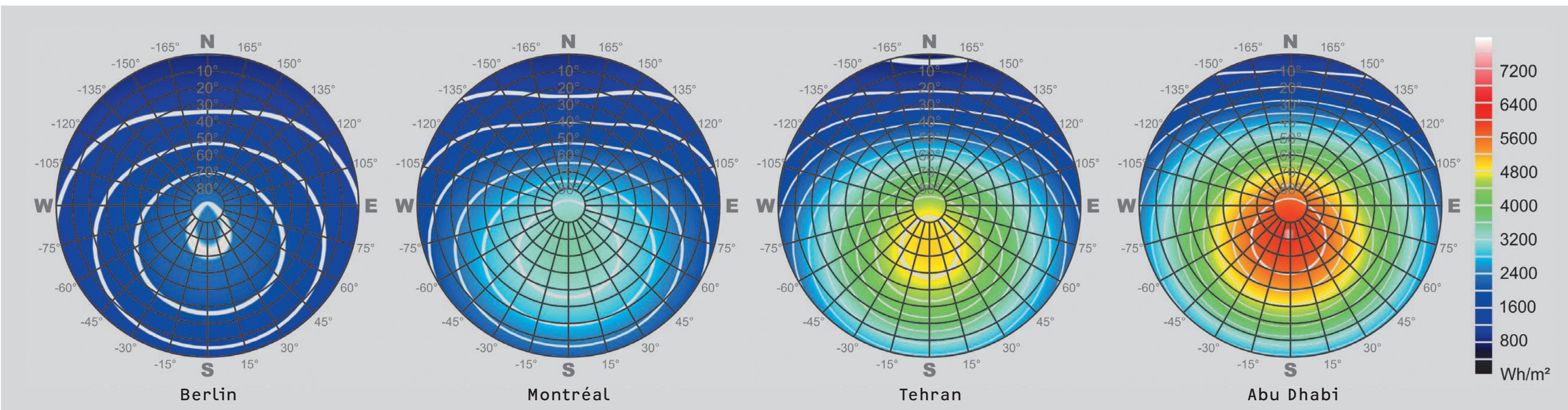


Fig. 287: Differences between the total amount of annual radiation in Berlin, Montréal, Tehran and Abu Dhabi

Energy	US	Canada	Norway	UAE	Iran	India	China	Australia	Germany	Saudi Arabia
Oil										
Proved reserves (Thousand million barrels)	35.0	173.9	7.5	97.8	157.0	5.7	17.3	3.9	—	265.9
Production (Thousand barrels daily)	8,905	3,741	1,916	3,380	3,680	894	4155	458	—	11,530
Consumption (Thousand barrels daily)	18,555	2,412	247	720	1,971	3,652	10,221	1,019	2,358	2,935
Refinery capacities (Thousand barrels daily)	17,388	2,063	310	710	1,892	4099	11,547	663	2,097	2,122
Natural gas										
Proved reserves (Billion cubic meters)	8,500	2,000	2,100	6,100	33,600	1,300	3,100	3,800	100	8,200
Production (MTOE)	619.2	140.9	103.4	46.5	144.5	36.2	96.5	44.1	8.1	92.5
Consumption (MTOE)	654.0	90.6	3.9	56.6	140.5	49.1	129.5	22.9	67.7	92.5
Coal										
Proved reserves (Million tons)	237,295	6,582	—	—	—	60,600	114,500	76,400	40,699	—
Production (MTOE)	515.9	35.2	—	—	—	228.8	1825.0	241.1	45.7	—
Consumption (MTOE)	437.8	21.9		—	0.9	298.3	1873.3	49.3	79.2	—
Others										
Nuclear energy Consumption (MTOE)	183.2	21.7	—	—	0.3	7.5	22.0	_	22.5	—
Hydroelectricity Consumption (MTOE)	63.2	86.0	32.3	—	2.9	26.2	194.8	4.1	4.8	—
Other renewable Consumption (MTOE)	50.7	4.3	0.5	< 0.05	< 0.05	10.9	31.9	2.8	26.0	—
Biofuels Production (MTOE)	27.3	0.9	—	—	—	0.3	1.7	0.2	2.9	—
Primary energy Consumption (MTOE)	2,208.8	328.8	48.1	89.3	234.2	563.5	2,735.2	125.7	311.7	222.2

MTOE = Million tons oil equivalent | Production/Consumption = Annual Production/Consumption in 2012

Tab. 5: Statistical overview of world energy in different countries (BP, 2013)

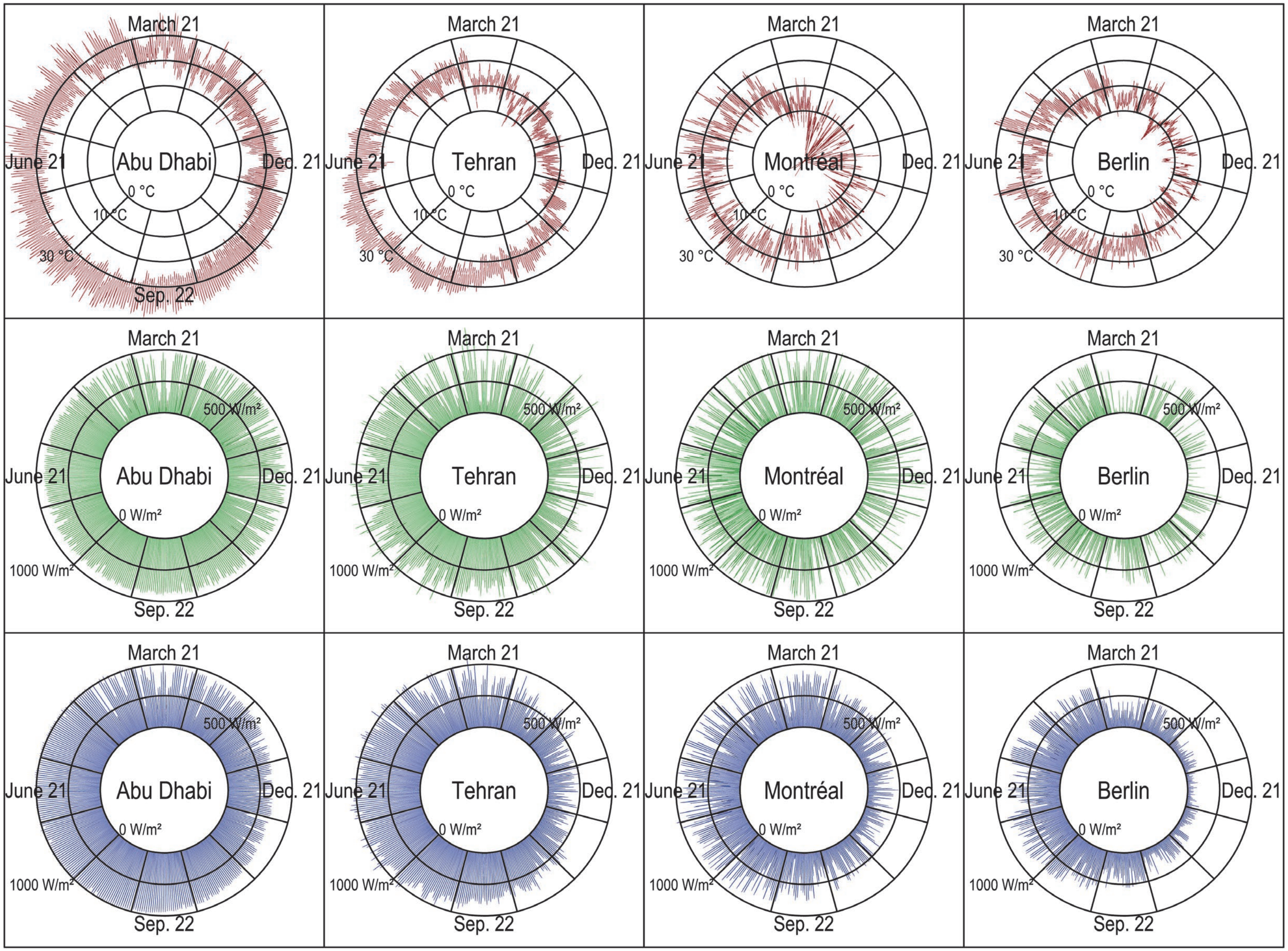


Fig. 288: SOLARCHVISION radial annual plot of hourly parameters, above: temperature, middle: direct beam radiation, below: total horizontal radiation (U.S. Department of Energy TMY files)

Figure 289 shows the availability of direct solar radiation on extremely cold days in Montréal with temperatures between -10°C and -30°C and the direct normal radiation exceeding 750W/m², sometimes even reaching 1000W/m². In other words, in each location the coldest and warmest temperatures most probably occur on sunny days. This simple fact increases the importance of considering the sun, both in planning buildings as well as outdoor areas, significantly. In fact on the coldest days of winter, the effect of having direct solar radiation on the building skin (e.g. windows) and in urban areas rises significantly as both the degree of need to shade/shine and the amount of solar radiation increases (a similar situation happens on the hottest days of summer when it is sunny). On other winter days, when it is completely cloudy, or when it snows, direct radiation decreases; however, in most of these cases, the need for direct radiation is low as the temperature is close to 0°C. Consequently, despite general belief, in cold areas, like what is seen in Canada, cloudy conditions should not be considered a convincing reason to plan buildings and urban quarters without a solar design. In contrast, solar studies are extremely helpful in cities with extreme conditions, whether cold or hot, simply because they are sunnier.

Figure 290 illustrates a pattern which has resulted from plotting extreme daily conditions during different months of several years (from 1953 to 2005) in Montréal. According to this graph, the number of days in which the temperature exceeds 0°C has increased slightly in the last decades.

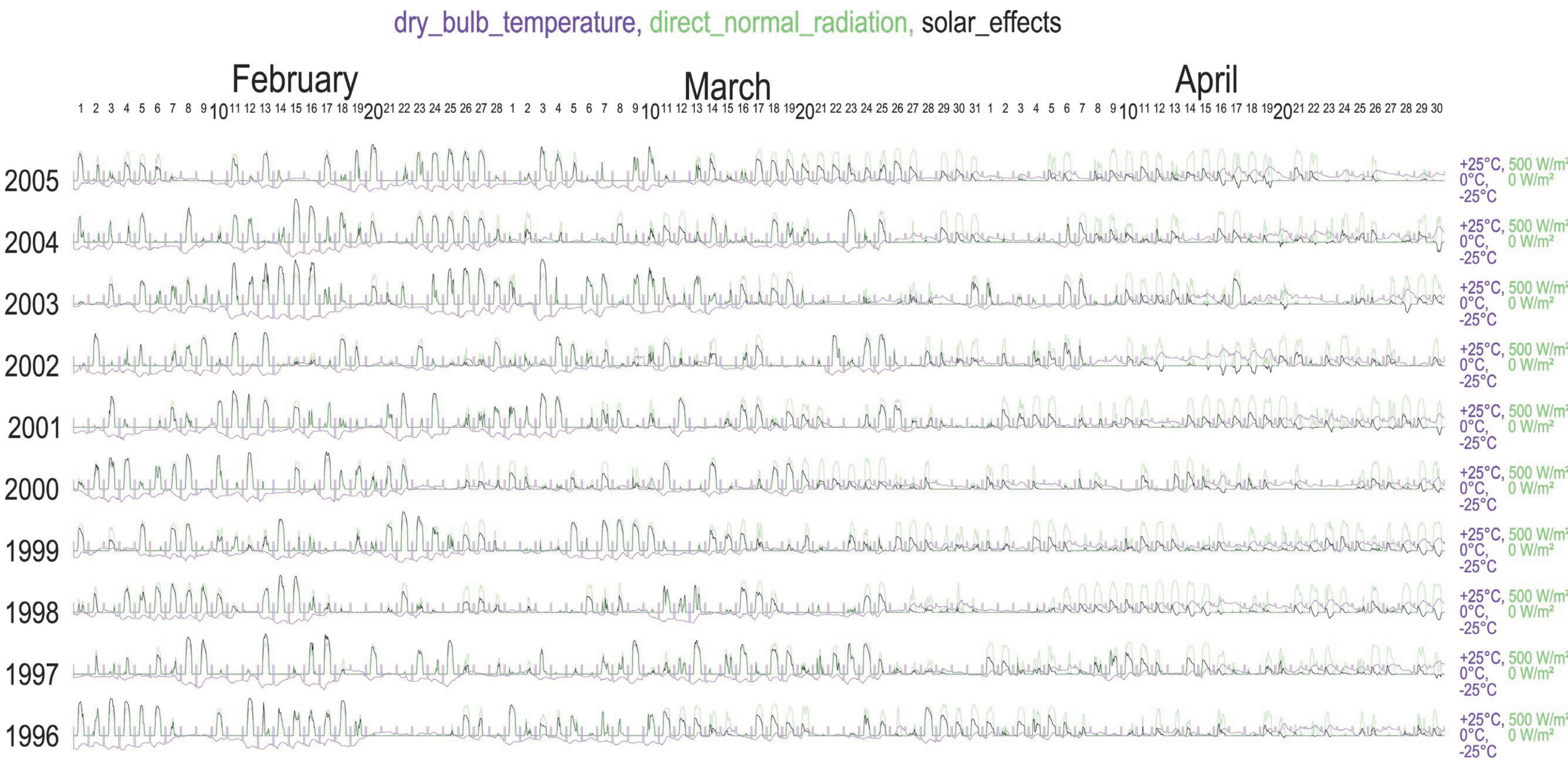


Fig. 289: SOLARCHVISION plot of hourly dry bulb temperature, direct normal radiation and solar effects for three months between 1996–2005 at Montréal Jean Brebeuf station at 45.50N, 73.62W (CWEEDS file, National Climate Data and Information Archive of Canada)

Moreover, as is presented in Figure 291, a remarkable increase in the amount of direct solar radiation over the years has produced more days with extreme conditions in summer, as well as in winter. All these studies confirm the significance of considerations for a harmonious adaptation to the sun.

As is illustrated in this book, a change in the hourly daily temperature in connection with solar gains can have a significant effect on the heat-

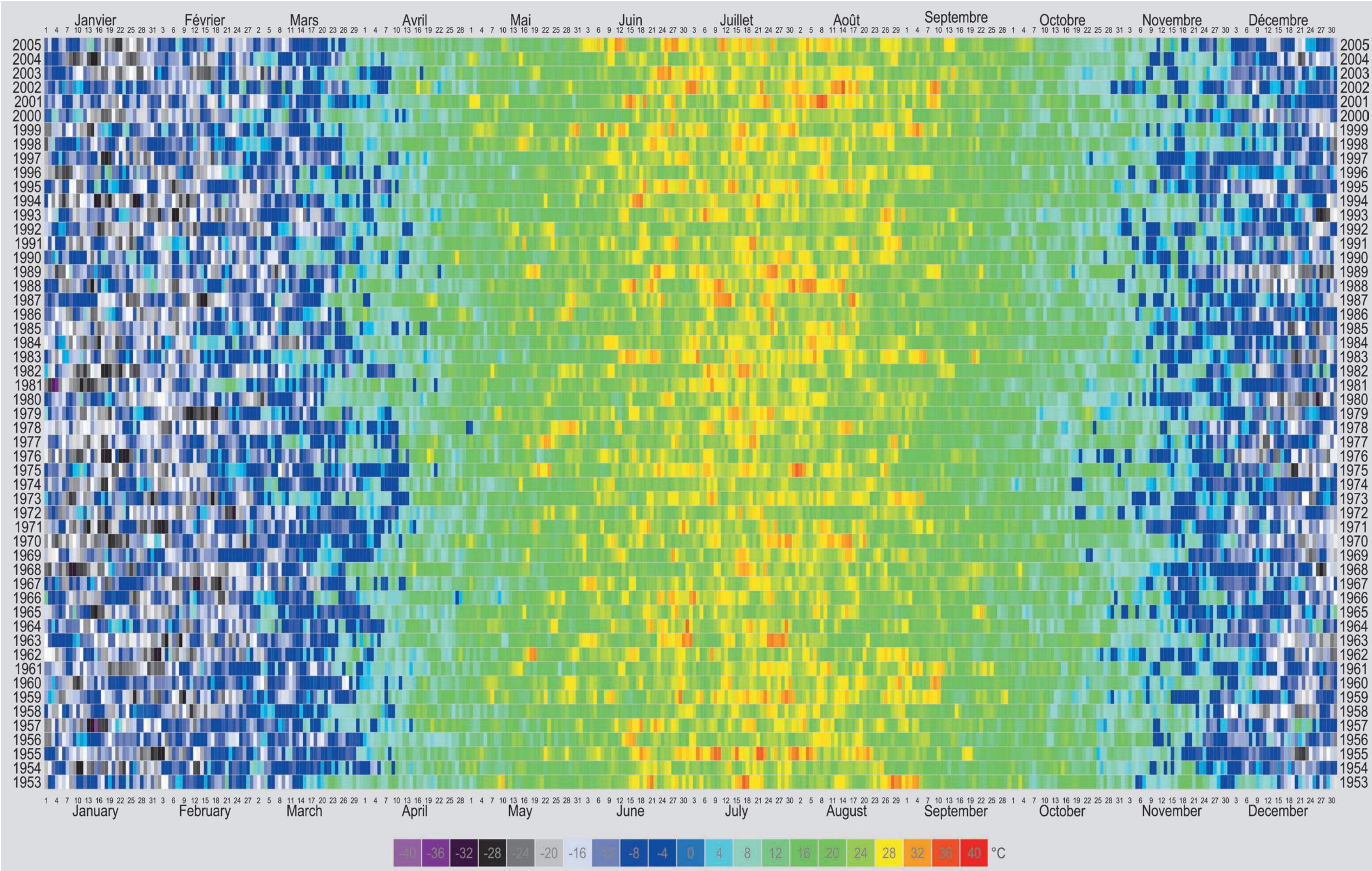


Fig. 290: SOLARCHVISION plot of the most extreme (based on a difference of +15°C) daily dry bulb temperature between 1953-2005 (Montréal Jean Brebeuf CWEEDS file), [yellow, orange and red: above +28°C, green: +25 to +15°C, dark blue: 0 to -10°C, white and gray: -15 to -25°C, black: below -28°C]

ing and cooling loads of buildings, as well as on the levels of comfort or discomfort inside and outside buildings. The urban fabric, building skin and the HVAC system must therefore respond effectively to the general solar-climatic patterns at each location.

Besides average environmental conditions, a study of the frequency and the impact of extreme environmental conditions at different intervals (e.g. day, year, decade, etc.) are also essential not only in architectural design and urban planning but also in other disciplines related to decision making and risk management processes.

In addition to meteorological and climate information with data available for a variety of time scales (year, decades), including valuable information for the design and planning of buildings, there are also a number of available weather forecasts and climate scenarios. These provide essential information which should be integrated in the design pro-

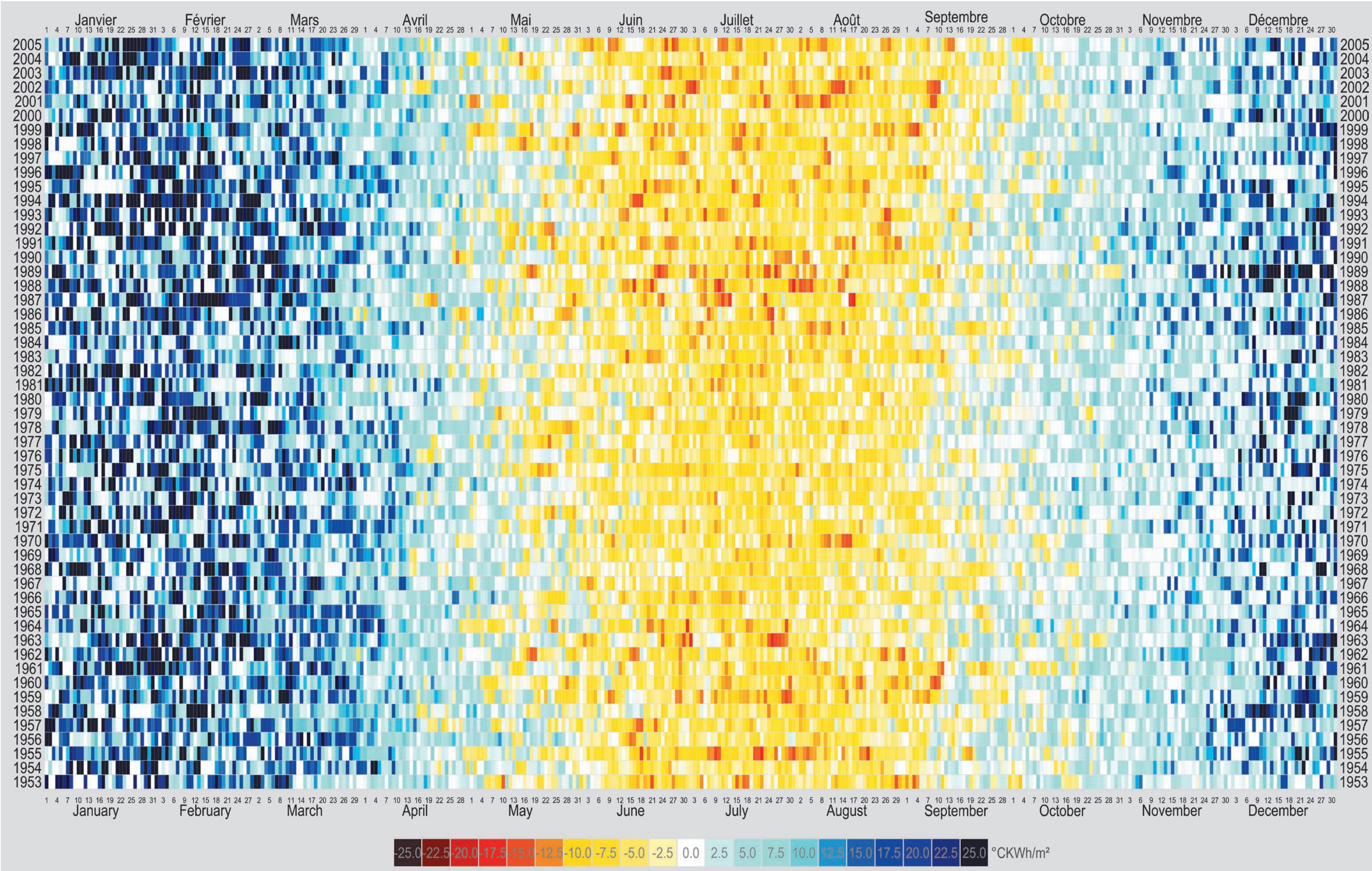


Fig. 291: SOLARCHVISION plot of the most extreme daily solar positive and negative effects between 1953–2005 (Montréal Jean Brebeuf CWEEDS file), [notes: base temperature = 15°C, red: shading/cooling is required, blue: solar energy can help to heat buildings and urban areas]

cess, the operation and system control management systems of buildings, neighborhoods and cities. While probabilistic forecasts from "ensemble" systems are already popular for a one to two-week period, the probability and scenario forecasts produced in ongoing studies should become important considerations with regard to climate change in the planning and designing of structures, which have expected lifetimes of several decades or longer. (see Poulin, 2013)

Despite thousands of successful products and projects concerning sustainable and green movements, many viewpoints still need to be changed and new horizons have to be discovered to find practical solutions to reduce the speed of ever increasing problems. On such an integrated and chaotic planet where we live, a theatrically awaited result will never be achieved without the cooperation of everyone. In this respect, it is most important to identify the gaps between the different disciplines to improve the integrity between the varied layers.

As an example and in order to improve energy and climate-related aspects, urban designers and architects must work together with environmental scientists to figure out the optimum boundary layers, which can best provide and maintain both internal and external comfort as well as health and safety for the inhabitants. The formation and adaptation of architectural and urban designs, in respect of the typical climatic conditions based on historical environmental data, has been discussed in detail in this book; weather forecasts are also essential pieces of information, which should be considered by integrating smart systems into the design and planning processes (Figure 292).

Planners, architects, engineers, clients, builders and future inhabitants should work together to make integrated decisions on buildings and cities. If this is not the case, the distance between what is wanted, what is proposed and what is completed will never change. To reflect on the current status of the construction industry, state-of–the-art know-how and awareness are fundamental aspects to increase the level of people's knowledge with regard to architecture and building services. If inhabitants are able to identify their own needs, and clients are also involved in this process, it becomes easier to make a distinction between good architecture and poorly designed buildings. Only awareness will enable users to step forward and approach architects to incorporate alternative and possibly more valuable aspects in the design. If this is not the case, the process as well as the products of designers, who take into consideration such aspects, will not be appreciated or perceived as something suitable for the future and not for today.

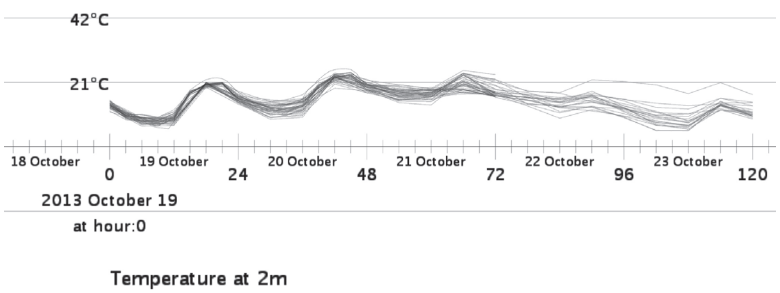


Fig. 292: Spaghetti-type line plot of a 5-day surface temperature forecast issued on the Jan 19 2013 00Z Environment Canada numerical weather prediction (NWP) models. This plot contains data from the RDPS, GDPS and GEPS (21 members) forecast models of Environment Canada

As the solar-climate aspects illustrated in this book affect not only the form and performance of buildings and cities but also deals with the health and life of inhabitants inside and outside buildings, they should be applied throughout the design process and operation phases of buildings and neighborhoods..

Considering the bold effect of municipalities, urban planners, architects and landscape architects in the process of decision making and decision taking, all stages of planning are important towards developing the right concepts for future spaces. No matter whether these spaces are indoors or outdoors, big or small, they should be created or modified in order to become safe, healthy, comfortable and climate responsive; the main objective of this book therefore is to describe and illustrate the fundamental role of a solar-climatic vision in architectural and urban planning.

In this respect, first the remarkable effects of the sun in different climates was presented. Afterwards, the methodology as well as a variety of practical solutions and solar-climatic guidelines were discussed for different scales (building skin, architectural and urban). These can be applied to improve the quality and the performance of cities and buildings for its inhabitants.

By applying SOLARCHVISION studies in the design process, the architect, landscape architect or urban planner, as well as the client and municipality experts, can simply generate the particular effects of the sun for each location. The SOLARCHVISION analysis introduces a new system based on mathematics, geometry and solar and climatic information for the determination of active and passive performance in the architectural and urban spatial design. In addition to this, by using materials accurately in their right position in the building skin, as well as the application of other technologies (with and without renewable energy), a meaningful design should always be at hand. Meanwhile, consideration of normal conditions and minimum and maximum extremes within historical data as well as short and long-terms forecasts can be applied in the design process to improve the relation between environment and architecture on different scales, ranging from planning buildings in a neighborhood, in a city, to designing shading devices for each orientation, including the optimization of solar collectors on roofs to the design of bus stops in respect of their particular local situations.

Hopefully this study will put the active and the passive strategies into a dialectical relationship to fashion a culture of solar-climatic vision in design, which traverses different scales (from a human scale to an urban and territorial as well as global scale) like the sun itself.

a) Although this book presents our best practices up until the end of 2013, the information contained in the book is subject to alteration without prior notice. In addition to possible errors, our understanding of the situation can either become more precise or completely changed over time as we move forward.

b) To simplify the description of the spatial analysis for readers, some advanced analyses of SOLARCHVISION, which are the results of optimized studies between different layers, are replaced with a more simple layer (i.e. percentage of solar-climatic performance).

c) Relative humidity and air movement have remarkable effects on the amount of evaporation which leads to heat loss from the body through the human skin. However, the building skin does not use the same concept of perspiration for cooling, but has particular effects on the performance of cooling systems. In the studies of this book, the corrective effects of wind and humidity are not applied to simplify the analysis or achieve basic concepts. In contrast, the effects of humidity and wind, which in most cases increase the impact, are applied in connection with the SOLARCHVISION analysis.

e) In addition to normal and extreme climates, the SOLARCHVISION analysis is able to foresee future needs of the building skin, as well as optimize and prepare for more appropriate layers in the building skin by applying short-term or long-term weather forecasts in the calculations of the solar-climatic analysis. On the other hand, by applying future climatic conditions, such as changes in temperature patterns and solar radiation around the world as the direct results of the global warming phenomenon, the SOLARCHVISION analysis can analyze the future challenges that are noticeable in the building skin, neighborhood and on an urban scale. This process can help not only in combating the heat island effect but also in providing future regulations for urban planning and architectural design.

f) There is still a lot of work to be done to keep the website of *www.solarchvision.com* going and hopefully to develop an interactive and online service as well as certain plug-ins to integrate the solar-climatic analysis into different softwares associated with architectural design and urban planning (e.g. ArcGIS, AutoCAD, ArchiCAD, 3DSMax, Maya, Rhino3D, SketchUP, Revit and TensileDraw), or within other building simulation tools.

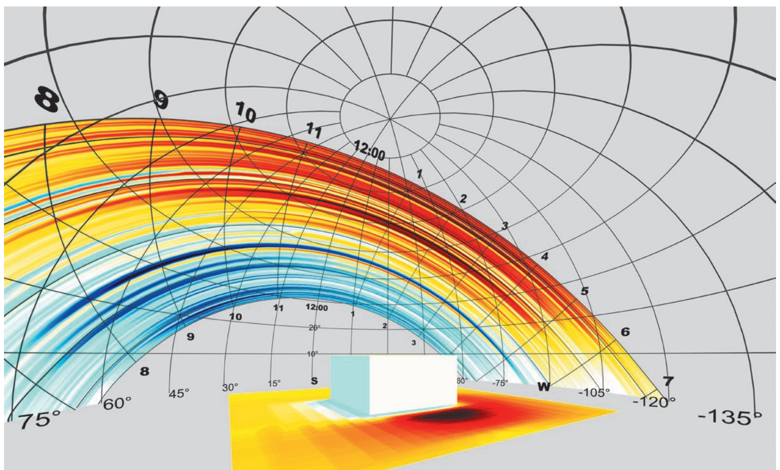


Fig. 293: Positive and negative effects of the sun and spatial analysis

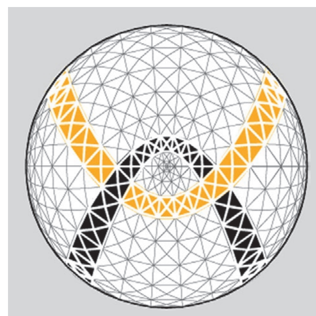


Fig. 294: www.solarchvision.com

d) Through the SOLARCHVISION analysis, the positive and negative effects of the sun can be multiplied by different values according to the costs for heating and cooling in each project. Thus the analysis can also be used to optimize the building costs (e.g. energy costs, life-cycle costs, etc.).

Although cities cover only 2% of the earth's land surface, they are responsible for 75% of global energy consumption as well as approximately 85% of global greenhouse gas emissions (Schäfer et al., 2010). Due to global climate change and massive population growth, as well as severe urbanization in Middle East and North African (MENA) regions, it is crucial to establish and conduct research projects for these areas. The research project *"Young Cities: Developing Energy-Efficient Urban Fabric in the Tehran-Karaj Region"* was set up and conducted in Iran for precisely these reasons.

The main objective of the Young Cities research project is to develop energy-efficient urban fabric in growing megacities. In addition to the Tehran-Karaj region in Iran, nine other similar projects of this kind are located in Asia, Africa and South America, including the countries India, China, Vietnam, Ethiopia, Morocco, South Africa and Peru. *"The basic idea and commitment of this German research program is to produce research results useful for growing megacities"* (Schäfer et al., 2010).

Following the initial phases in 2004, different dimensions were introduced between 2007 and 2013 to cover a variety of aspects, as listed in Figure 295.

The SOLARCHVISION research on Young Cities studies the relation between solar and climatic information and architectural design. Before a solar-climatic design can actually commence, the location of the site must be assessed carefully. In addition to latitude, longitude and elevation, the topography and solar-climatic historical data are essential pieces of information. All findings must be gathered, assessed and used appropriately.

The city of Hashtgerd New Town is located at the geographical coordinates of 35.9 N/50.7 E at an approximate height of 1,300 m above sea level, 30km west of Karaj and 65 km west of Tehran. The case study of the Young Cities research project is located in Hashtgerd New Town, northeast of Hashtgerd.

Strategic Dimension 1 **Urban Development and Design**	*Strategic Dimension 2* **Urban Infrastructures Systems**	*Strategic Dimension 3* **Design, Structure and Engineering**	*Supporting Module*
Urban Planning & Design	Energy Management	Design, Structure & Materials	Project Management
Architecture & Design	Water & Wastewater Management	Architecture & Engeneering	Environmental Assessment
Landscape Planning	Integrated Urban Technologies	Architecture & Energy	Capacity Development
Transport & Mobility			Awareness Raising
Climatology			

Fig. 295: Young Cities' structure

Figure 296 presents a 3-dimensional topographic map of the Shahre Javan Community. It has been used for the urban design and pilot project of the Young -Cities Research Project and was created to perform the SOLARCHVISION spatial analysis with greater accuracy and in a defined urban fabric. As can be seen in the diagram, the 660 × 660m plot is turned east by 15°; the height difference between the highest and lowest point is 45 m.

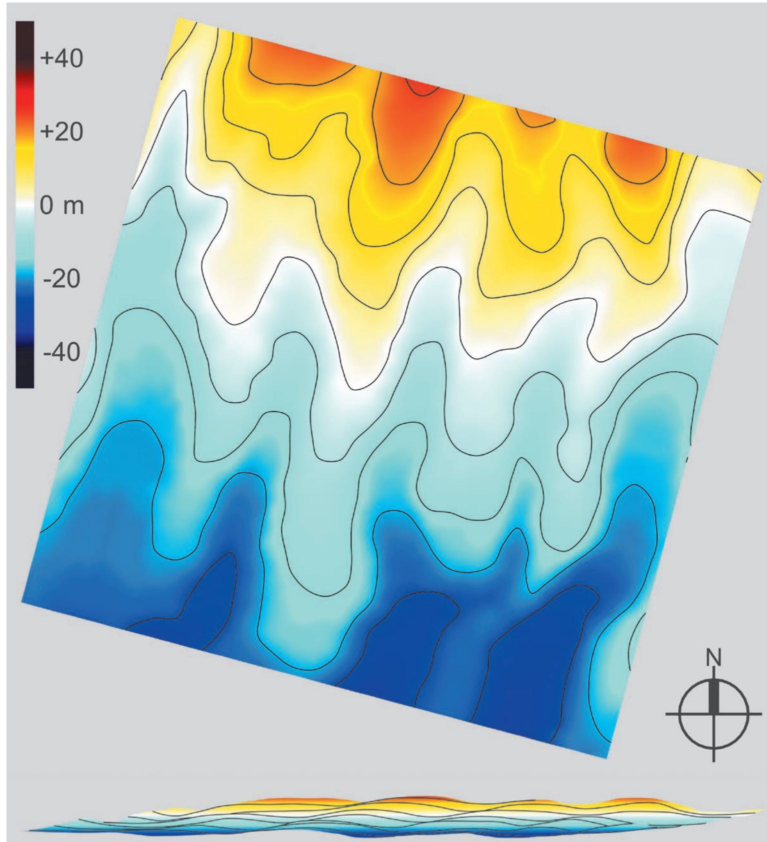


Fig. 296: Land elevations and orientation of the Shahre Javan Pilot Community in Hashtgerd New Town

5.1 Climatic Information and Basic Design

As is described before, solar-climatic data should be applied during the planning stage to advance the architectural form and its relation with the environment. It is far easier to use long-term records with a high level of accuracy than data from a single year riddled with inaccuracies.

The volume 06 of the *Young Cities Research Briefs* discusses detailed information on different sources of data related to the amount of solar radiation in Iran. In regard to these studies, for the case of Hashtgerd, only two sources can be recommended as reliable inputs for different building simulation tools:

1. Meteonorm 6.0 TMY (typical meteorological year) file,
2. SOLARCHVISION calculations of direct and diffuse radiation based on long-term IRIMO monthly averages of the total solar radiation on a 1 m²-large horizontal surface.

It is also worth noting that the other hourly sources for Tehran, as well as interpolations and extrapolations for Hashtgerd New Town, which were available at the time, included implausible values for direct and diffuse solar radiation, as reported in *"SOLARCHVISION Studies on Young-Cities Project"* in greater detail.

Yet, there was another complex issue concerning the hourly models of temperature. For instance, the interpolated data for Hashtgerd New Town using Meteonorm 6.0 includes 3–4°C higher values compared to other data, such as climate data prepared by the "Dimension Climatology" of the Young Cities Project (Free University Berlin). Temperature statistics from Bagh_Kousar station [36:0 N, 50.6 E], which have been available since 1986, demonstrate the validity of the Dimension Climatology's calculations for the hourly temperature model of Hashtgerd New Town. In consideration of this model and by using 21°C as the base temperature, the heating and cooling periods can be determined by the dates May 6 and October 7, which means that solar radiation can lead to serious overheating in buildings for five months of the year. On the other hand, for 7 months of the year, the sun can have desirable effects on the building skin and outdoor areas in the urban fabric. These positive and negative effects of the sun are illustrated in Figure 298. A comparison of this diagram with similar graphs for Tehran in Figure 74 shows that colder and longer winters in Hashtgerd New Town benefit even more from the sun; however, there are still remarkable negative effects, which should be considered seriously in planning and design.

To conclude the discussion on solar-climatic data for a country like Iran with diverse climates, as well as great investments in constructions and buildings, it is necessary to draw attention to the fact that the availability and reliability of data is essential to conduct even a small-scale project.

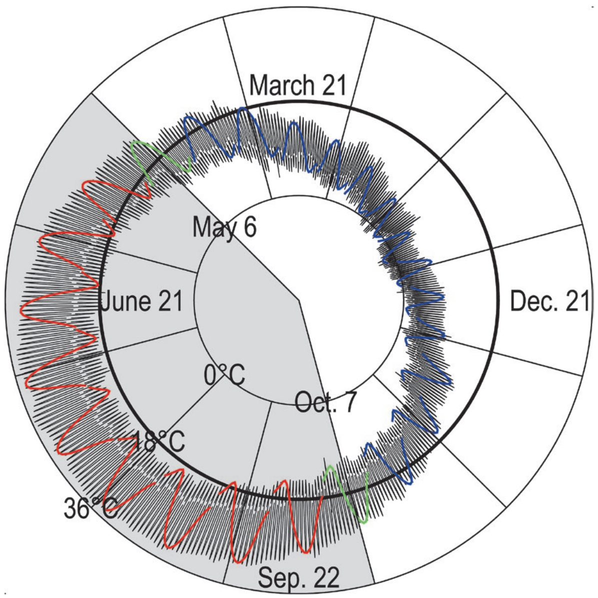


Fig. 297: SOLARCHVISION radial annual plot of hourly temperature (Climatology—FU Berlin) with a 15-day hourly average in the heating and cooling periods

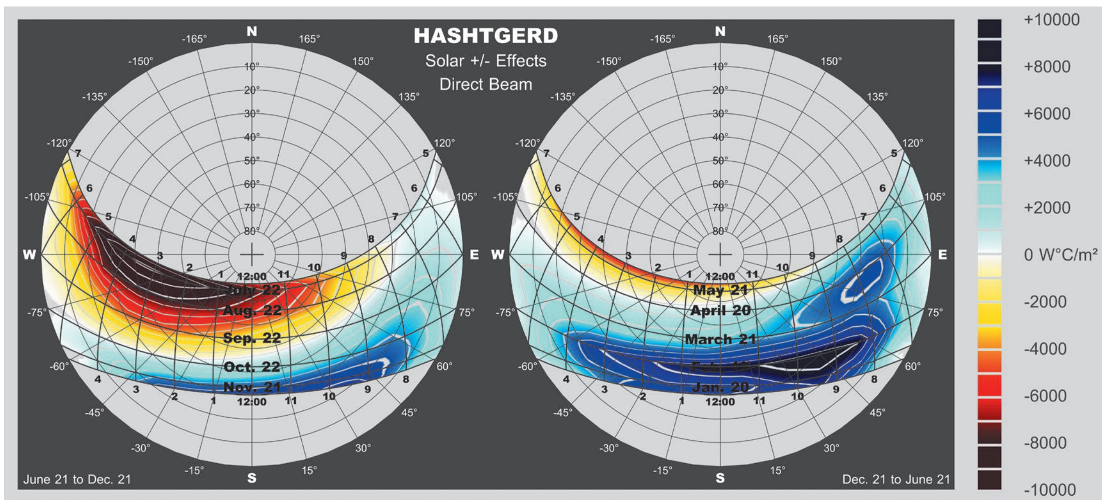


Fig. 298: Plot of positive and negative effects of direct solar radiation in Hashtgerd New Town

5.2 Urban and Neighborhood Analysis

Based on the solar-climatic information of Hashtgerd New Town, the active and passive SOLARCHVISION analysis of urban mass and spaces in the Shahre Javan Community pilot project are presented here. The graphs illustrate the annual amount of direct and diffuse solar radiation as well as the design performance of building geometries in relation to the advantages and disadvantages of solar radiation during the heating and cooling periods.

Regarding these studies, shade during the heating period and exposure to the sun during the cooling period can generate unfavorable situations for east/west-oriented paths during most parts of the year. Based on this proposal, it is important to improve the solar-climatic performance

Fig. 299: SOLARCHVISION active analysis, annual solar radiation model of the Shahre Javan Community

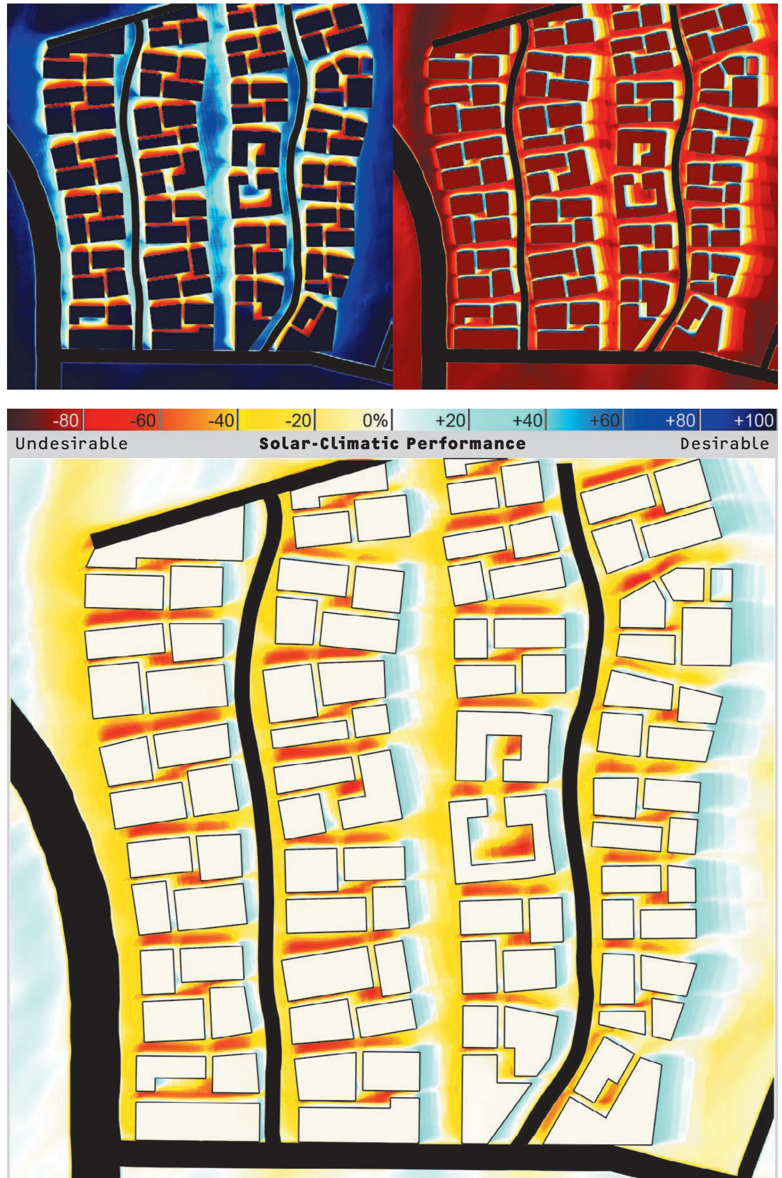


Fig.300–302: SOLARCHVISION passive analysis of the Shahre Javan Community during different periods, above-left heating period, above-right: cooling period, bottom: annual cycle

of these aspects (the red and yellow areas in the annual passive analysis) using optimized reflectors and shading devices, as well as trees, and repeat the analysis.

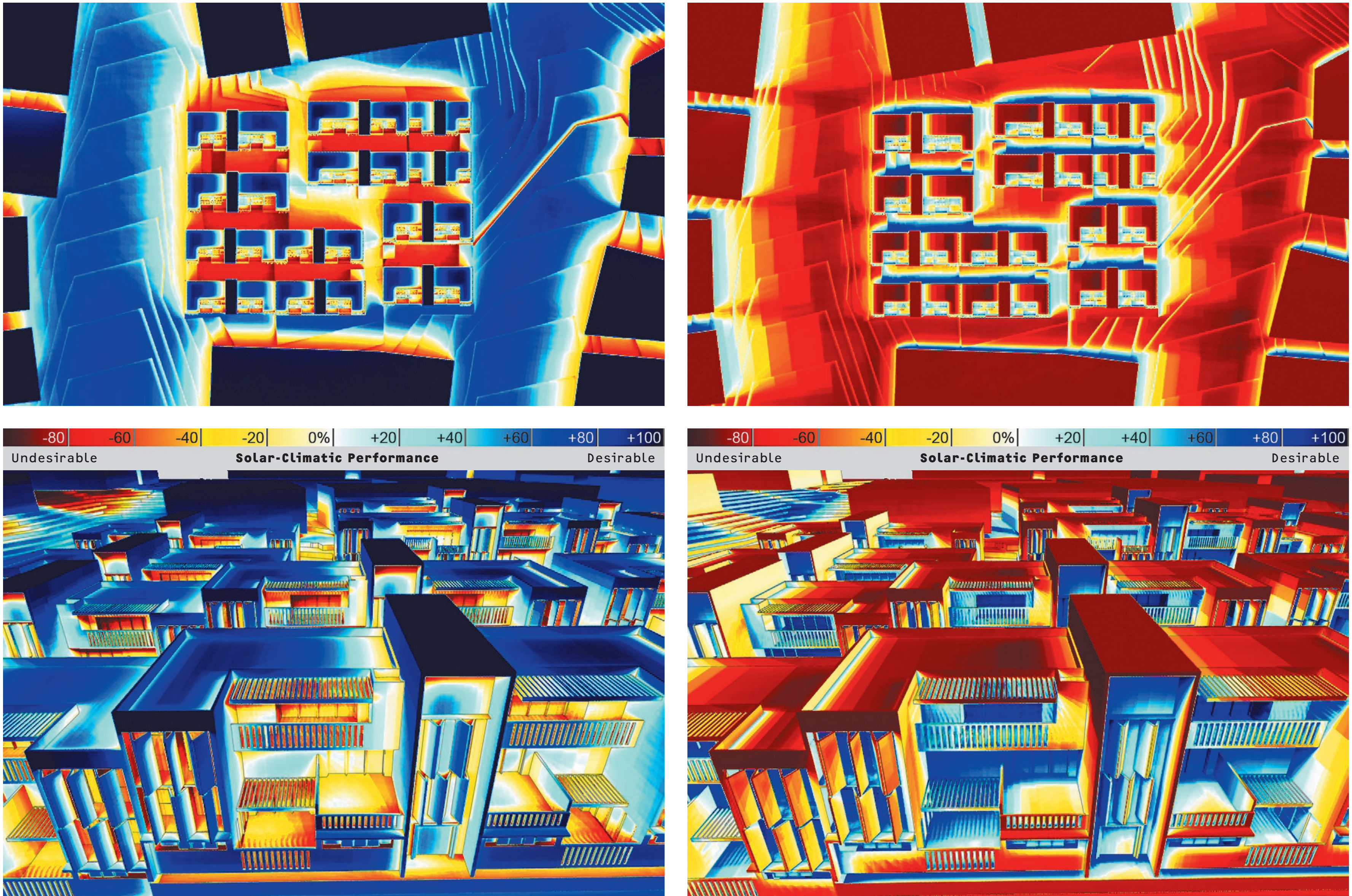


Fig. 303–306: SOLARCHVISION passive analysis on a neighborhood scale in different periods, left: heating period, right: cooling period

At a smaller scale, residential units were studied during the cooling and heating periods in the same way. The heating period analysis above shows the negative effects of shading devices and how these affect the lower floors, as well as the outdoor areas in this urban fabric. The study of the south facade illustrates the effects of designated shading devices on the building skin during the design process. The blue areas in the cooling period analysis demonstrate the proper functioning of shading devices during this period. Accurate decisions should be made to improve unfavorable areas, both during the heating and cooling periods.

5.3 Development of the New Generation Office Building

The two main objectives of the pilot project *New Generation Office Building* were:

1. reduction of the total and primary energy consumption in comparison to existing office buildings in Iran
2. improvement of thermal comfort in the interior predominantly by means of the architectural design as the main source for saving energy.

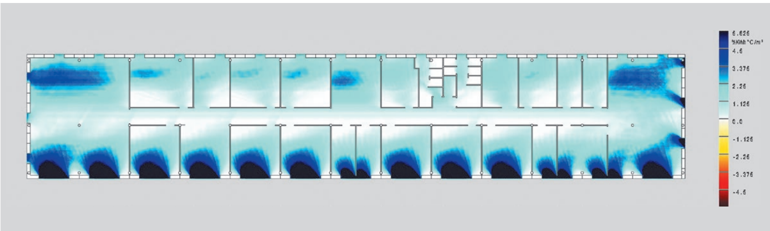
The design of the pilot buildings is based on a series of studies, which investigates the thermal behavior of office buildings. Different architectural factors that affect the energy demand are considered, including orientation, window ratio in all cardinal directions, shading devices, etc. A variety of energy simulation tools, in particular DesignBuilder, are applied for the studies.

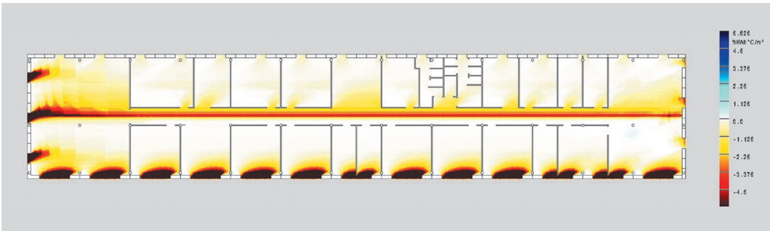
The importance of the sun, both for indoor and outdoor spaces as well as the building skin, was studied during the course of the SOLARCHVISION program. Figure 309 shows the annual-cycle of the SOLARCHVISION passive analysis using a 3-dimensional model of the first proposal assuming that all solar radiation, which is received on the building skin, is transmitted through transparent areas (e.g. windows and skylights) and blocked by opaque surfaces (e.g. roof, walls, and shading devices). Such an analysis can discover the general capacity of different spaces in the building for receiving positive and negative solar effects. The data can help architects to develop layouts and improve the design of the building skin, if required. It can also help to select and position the heating and cooling equipment of the HVAC system.

The radiation models as well as the advanced daylight analysis (using other tools), should be used in a similar way to study and improve the daylight performance of the interior.

In order to improve the energy performance, as well as thermal and visual comfort, within the New Generation Office Building, several studies, including SOLARCHVISION analyses, are performed, which have all accompanied the design process of this pilot project. The results of these studies help to find a responsive form for the building and enhance its performance.

The final form of the building, which is different from the design presented here, can be found in full detail in *"Green Office Buildings: Low Energy Demand through Architectural Energy Efficiency"*. Volume 08 of *Young Cities Research Paper Series* entitled *"Green Office Buildings"* and also Volume 06 of Young Cities Research Briefs entitled *"SOLARCHVISION Studies on Young-Cities Project"* discuss the application of different simulation tools to optimize the New Generation Office Building.





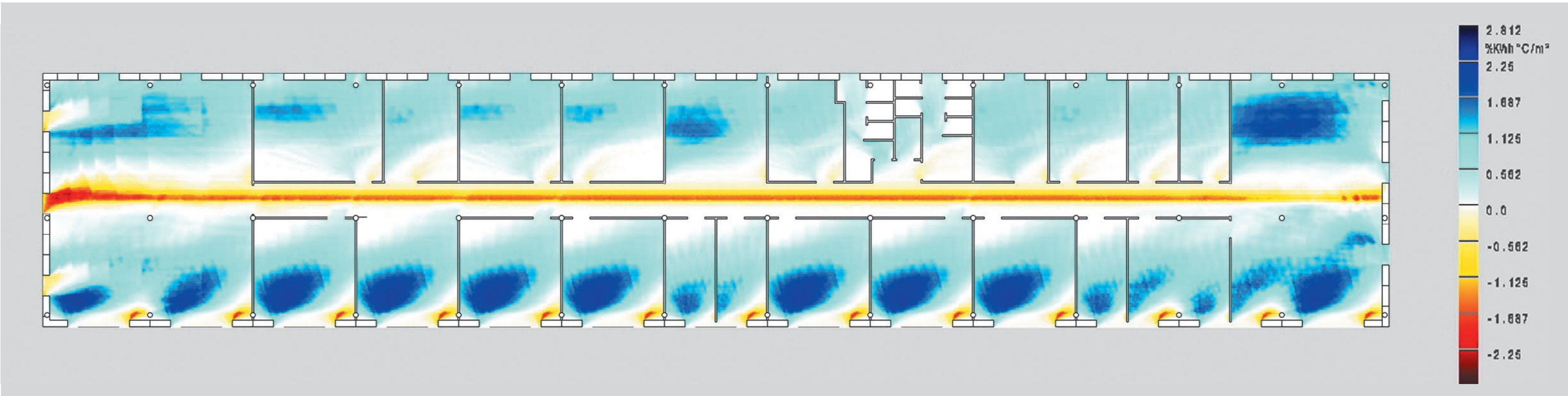
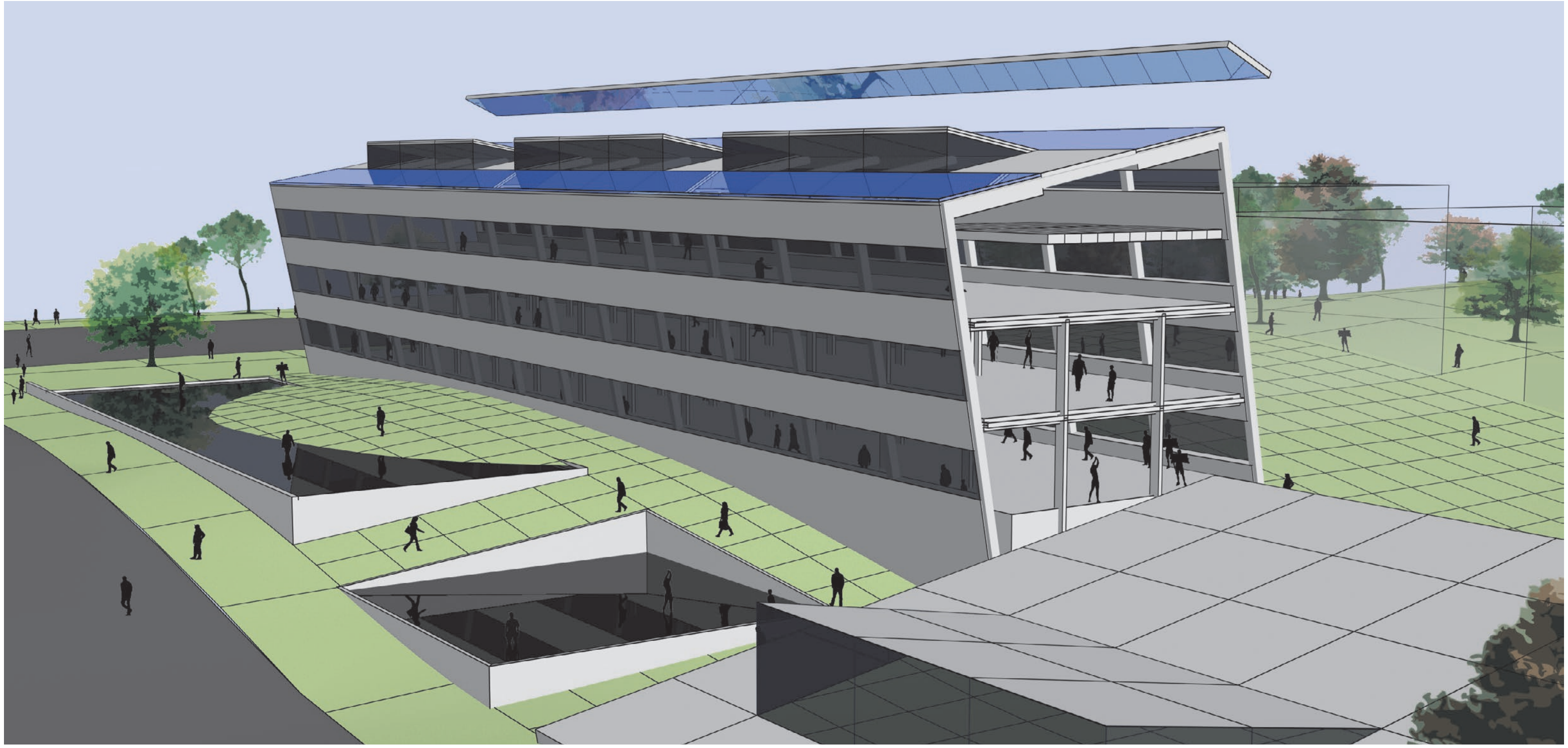
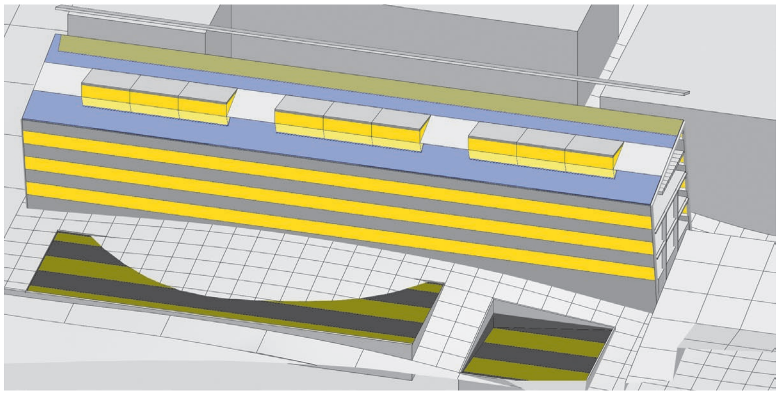


Fig. 307–308: The SOLARCHVISION passive analysis, upper floor plan of the New Generation Office Building (first proposal), left: heating period, right: cooling period
Fig. 309: Annual-cycle of the SOLARCHVISION passive analysis, upper floor plan of the New Generation Office Building (first proposal)

Figure 310 presents an alternative to the initial proposal of the pilot project. In addition to replacing the vertical windows by horizontal ones, the building geometry has a 10° inclination and optimized solar collectors; reflectors and pools are used to achieve the following results:





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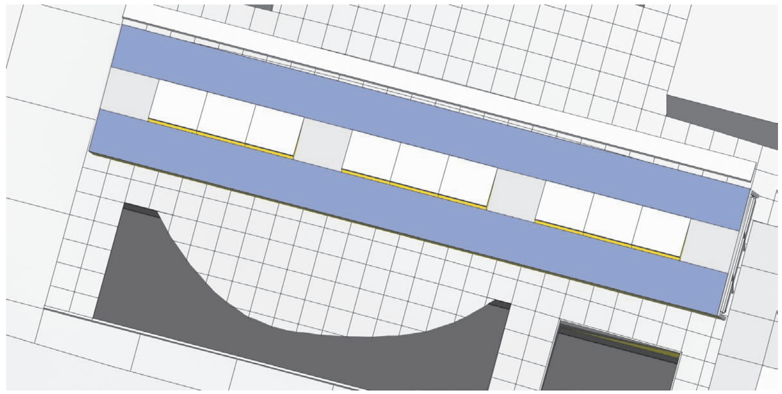

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Fig. 310–312: Human scale and solar perspectives for one of the alternatives studied within the New Generation Office Building pilot project

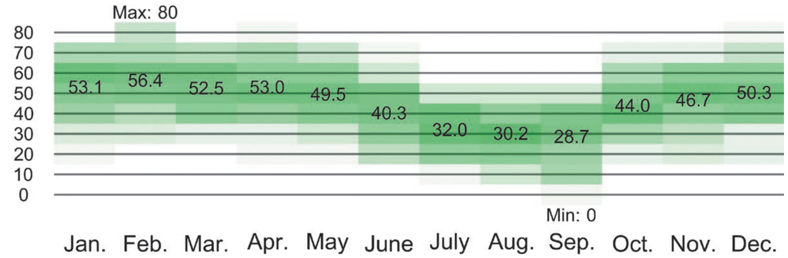
1. Self-overshadowing of the south side: in this case, the amount of desirable solar gains in the heating period is not changed significantly; however, there is no need for external shading devices and only internal shading devices are necessary to control the amount of daylight.
2. More daylight on the north side as well as better performance of reflective surfaces in the heating period which direct sun onto the north side.
3. A friendly relationship with the environment and a slight slope from north to south
4. Compact and simple form
5. Flexible space on the upper level for future extensions

In Figures 311 and 312, the amount of direct solar radiation received on the building skin through the windows is expressed by the yellow areas.

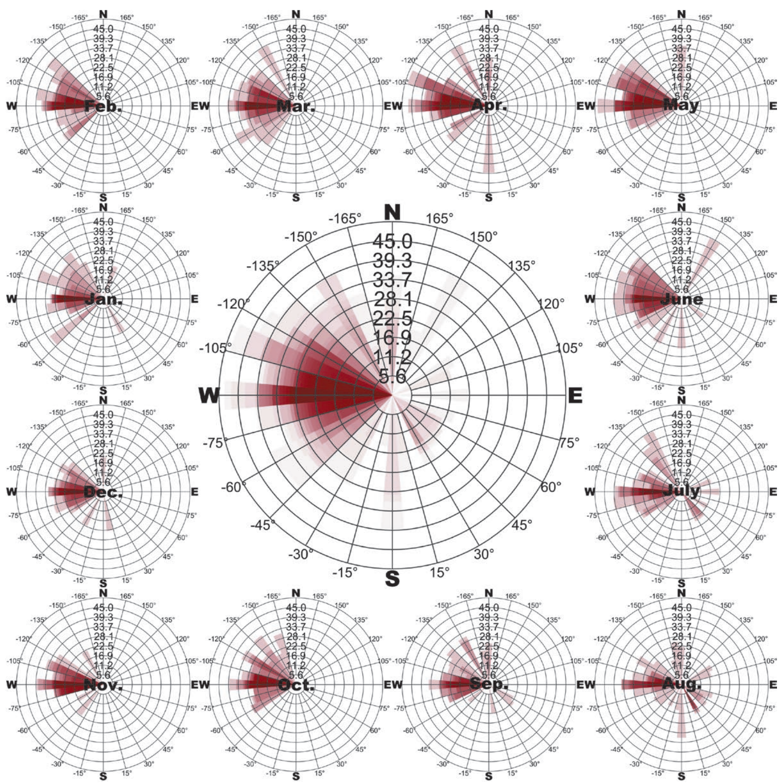
By showing how solar radiation can be blocked in summer and increased in winter, the diagrams demonstrate that an understanding of the sun path, as well as a solar-climatic vision in each location, can improve the architectural form and the use of materials. In a word “***if we ever knew exactly where the light was coming from, getting there would be easy***” (May, 1992).

V
Appendix

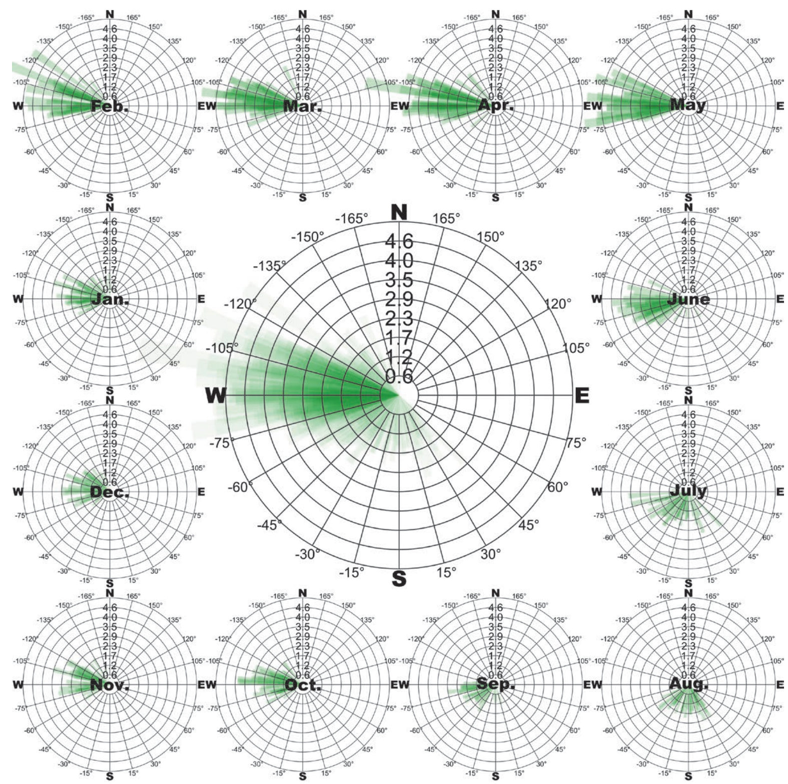
Additional Figures



Wind steadiness in percent

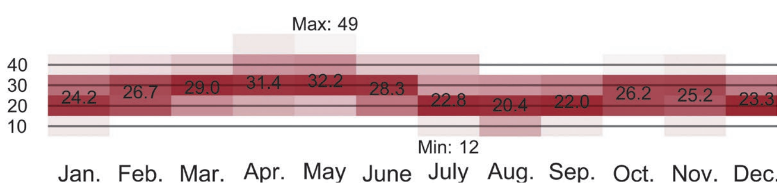


Fastest wind direction and speed in knots

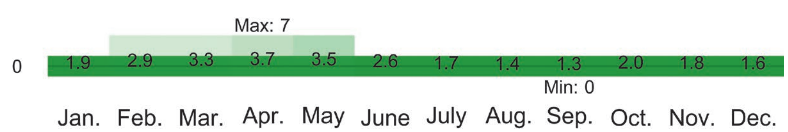


Prevailing wind direction and speed in knots

Fig. 313: SOLARCHVISION plots for wind in Tehran with monthly means and extremes as well as the probabilities resulting from the 1951 to 2005 records (IRIMO)



Fastest wind speed in knots



Prevailing wind speed in knots

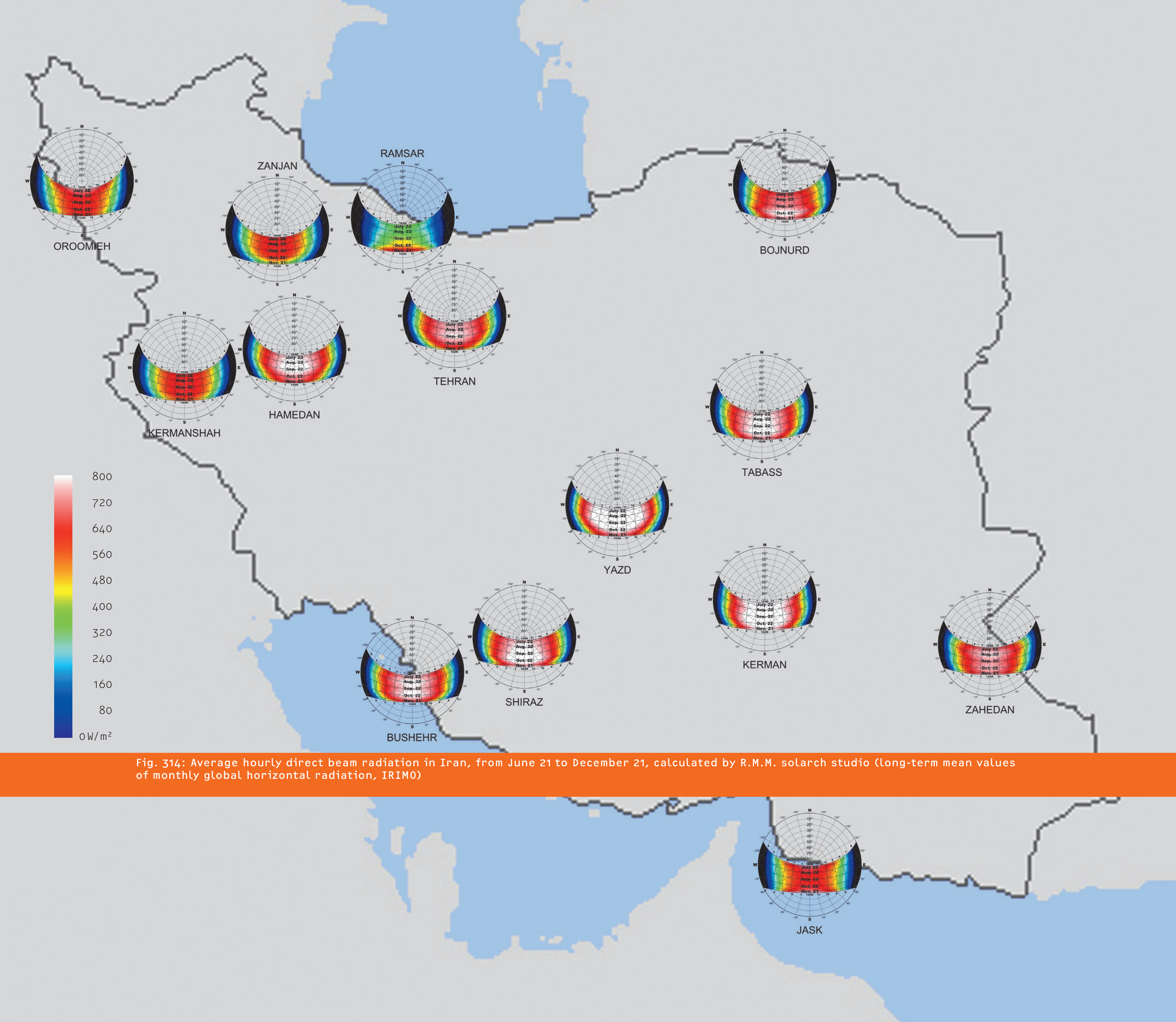


Fig. 314: Average hourly direct beam radiation in Iran, from June 21 to December 21, calculated by R.M.M. solarch studio (long-term mean values of monthly global horizontal radiation, IRIMO)

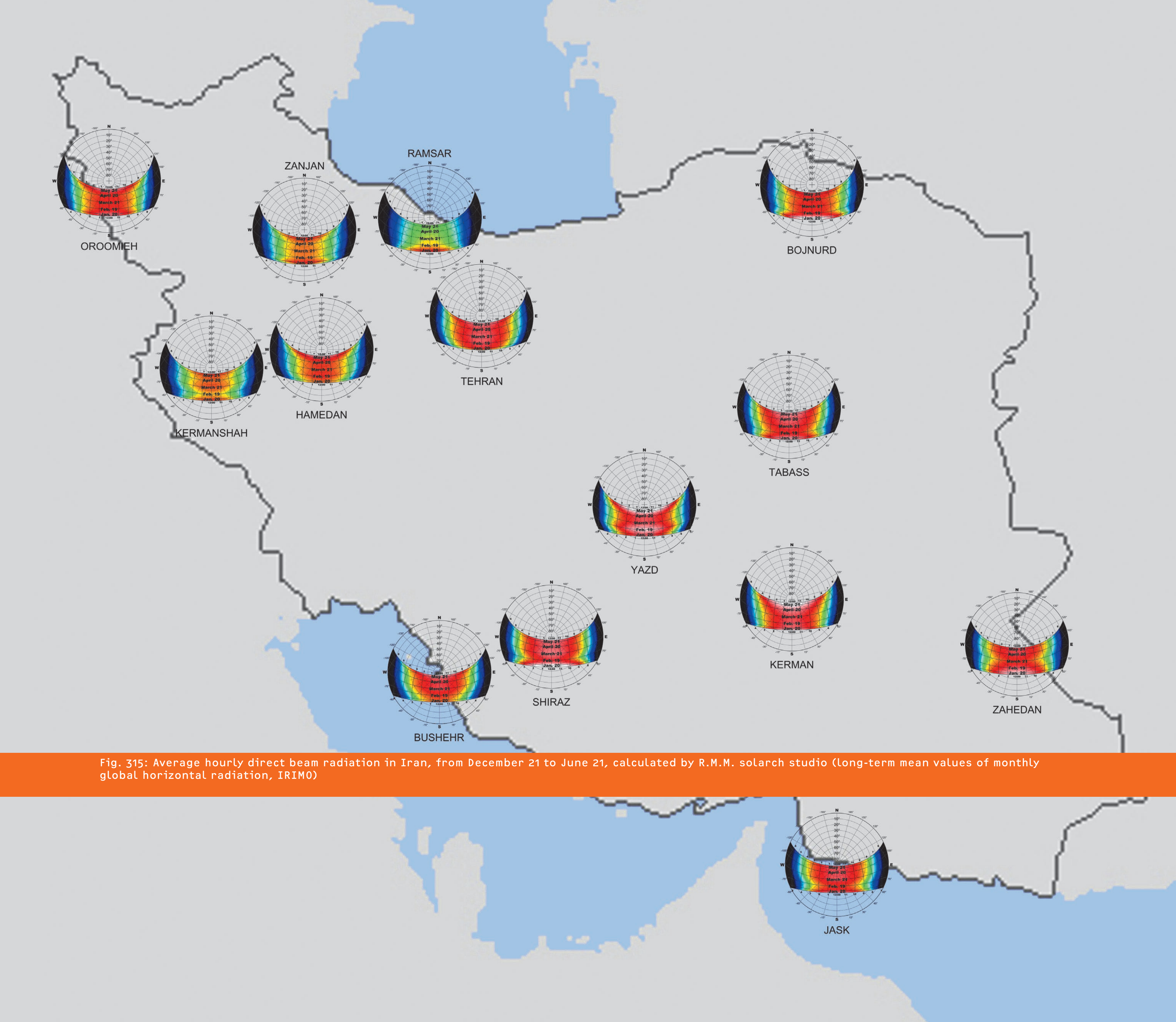


Fig. 315: Average hourly direct beam radiation in Iran, from December 21 to June 21, calculated by R.M.M. solarch studio (long-term mean values of monthly global horizontal radiation, IRIMO)

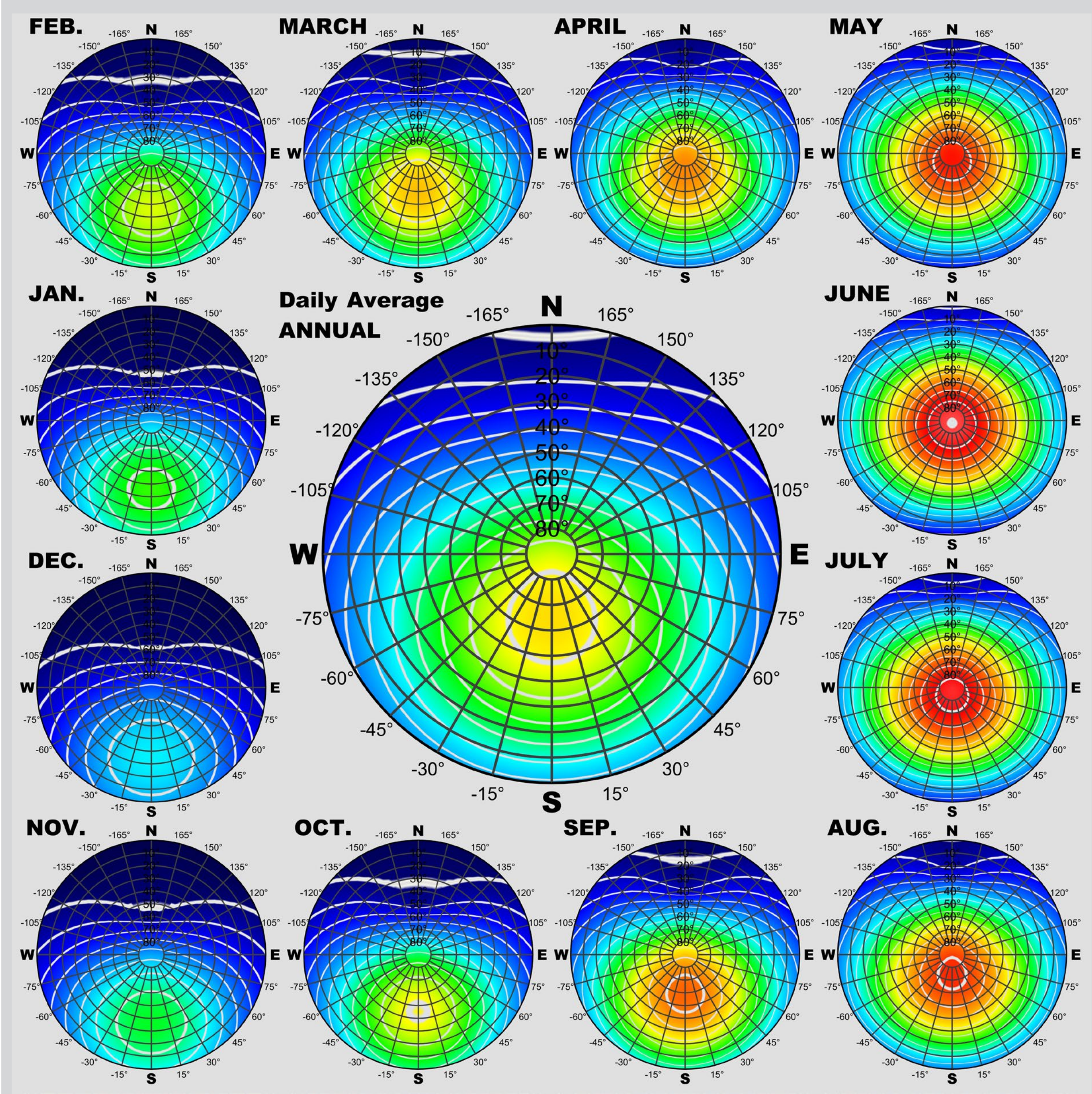
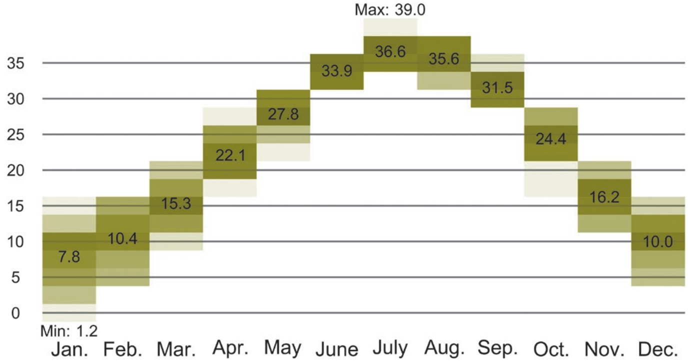
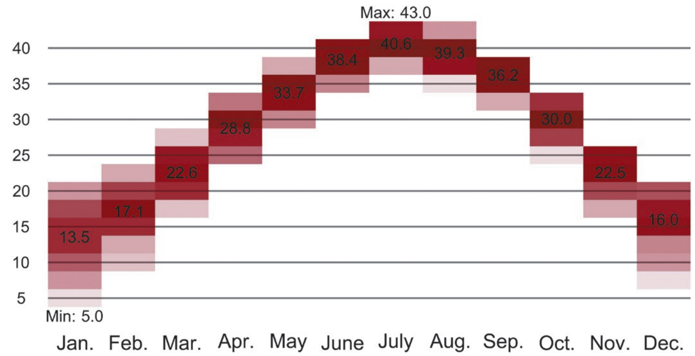


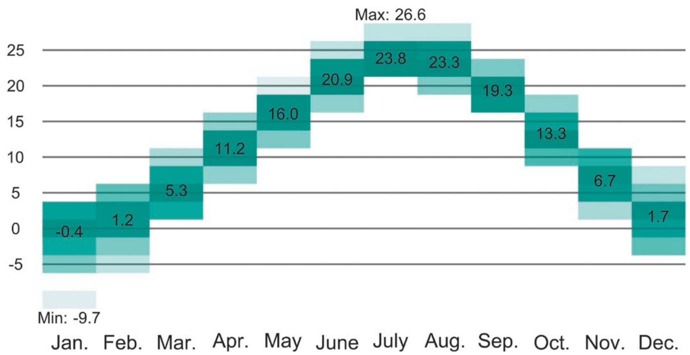
Fig. 316: Average total daily radiation on different surface orientations and inclinations in Tehran in different months as well as in the annual cycle,calculated by R.M.M. solarch studio (Figures 109–112)



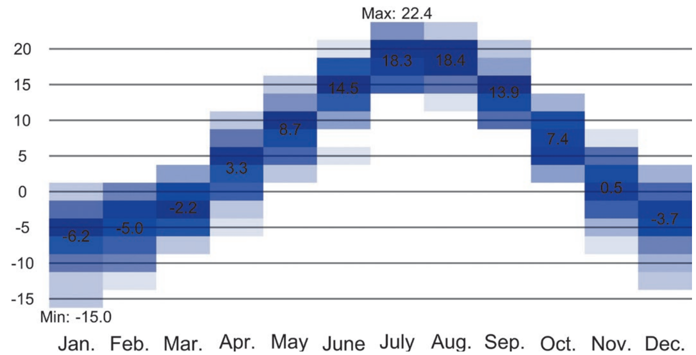
Average maximum temperature in °C



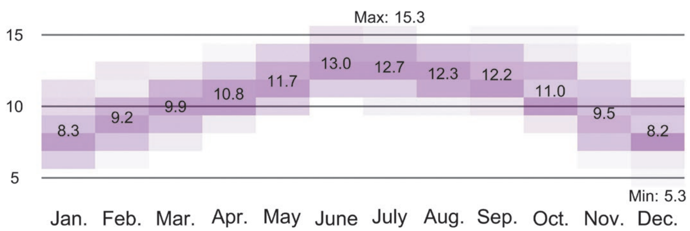
Highest temperature record in °C



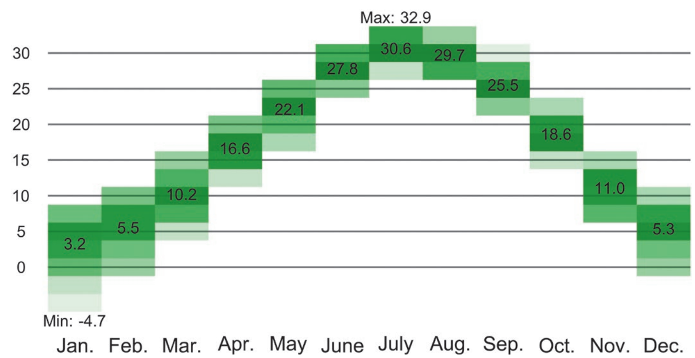
Average minimum temperature in °C



Lowest temperature record in °C

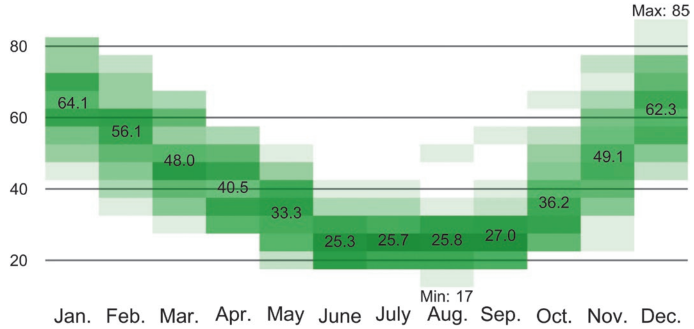


Difference between average maximum and minimum temperature in °C

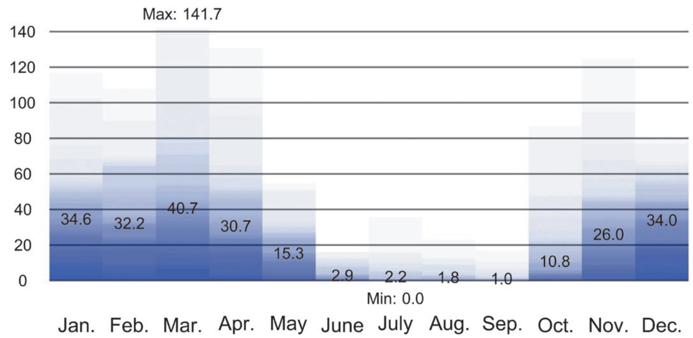


Average dry bulb temperature in °C

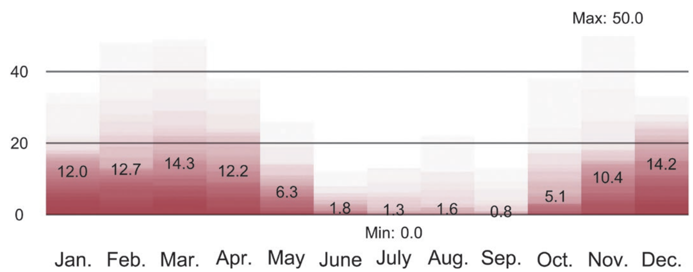
Fig. 317: SOLARCHVISION plots for air temperature in Tehran with monthly means and extremes as well as the probabilities resulting from the 1951 to 2005 records (IRIMO)



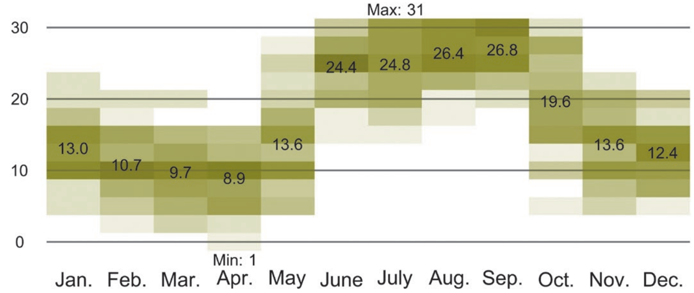
Average relative humidity in percent



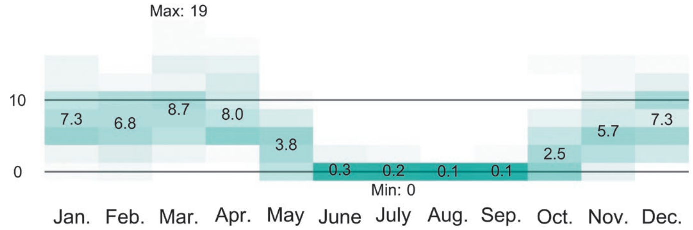
Total precipitation in mm



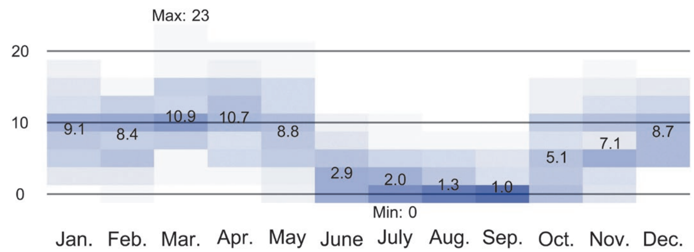
Greatest daily precipitation in mm



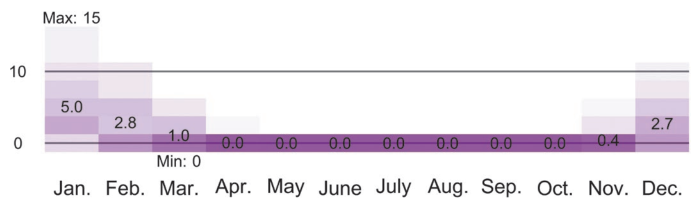
Number of clear days



Number of cloudy days

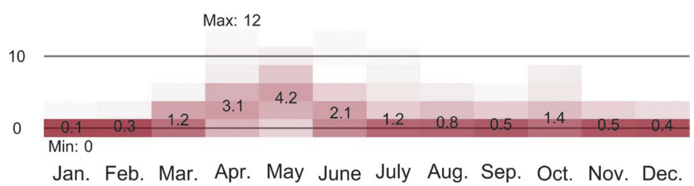


Number of days with precipitation

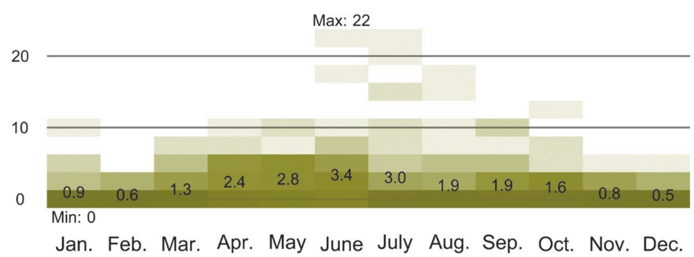


Number of days with snow or sleet

Fig. 318: SOLARCHVISION plots for other environmental factors in Tehran with monthly means and extremes as well as the probabilities resulting from the 1951 to 2005 records (IRIMO)



Number of days with thunder storms



Number of days with dust

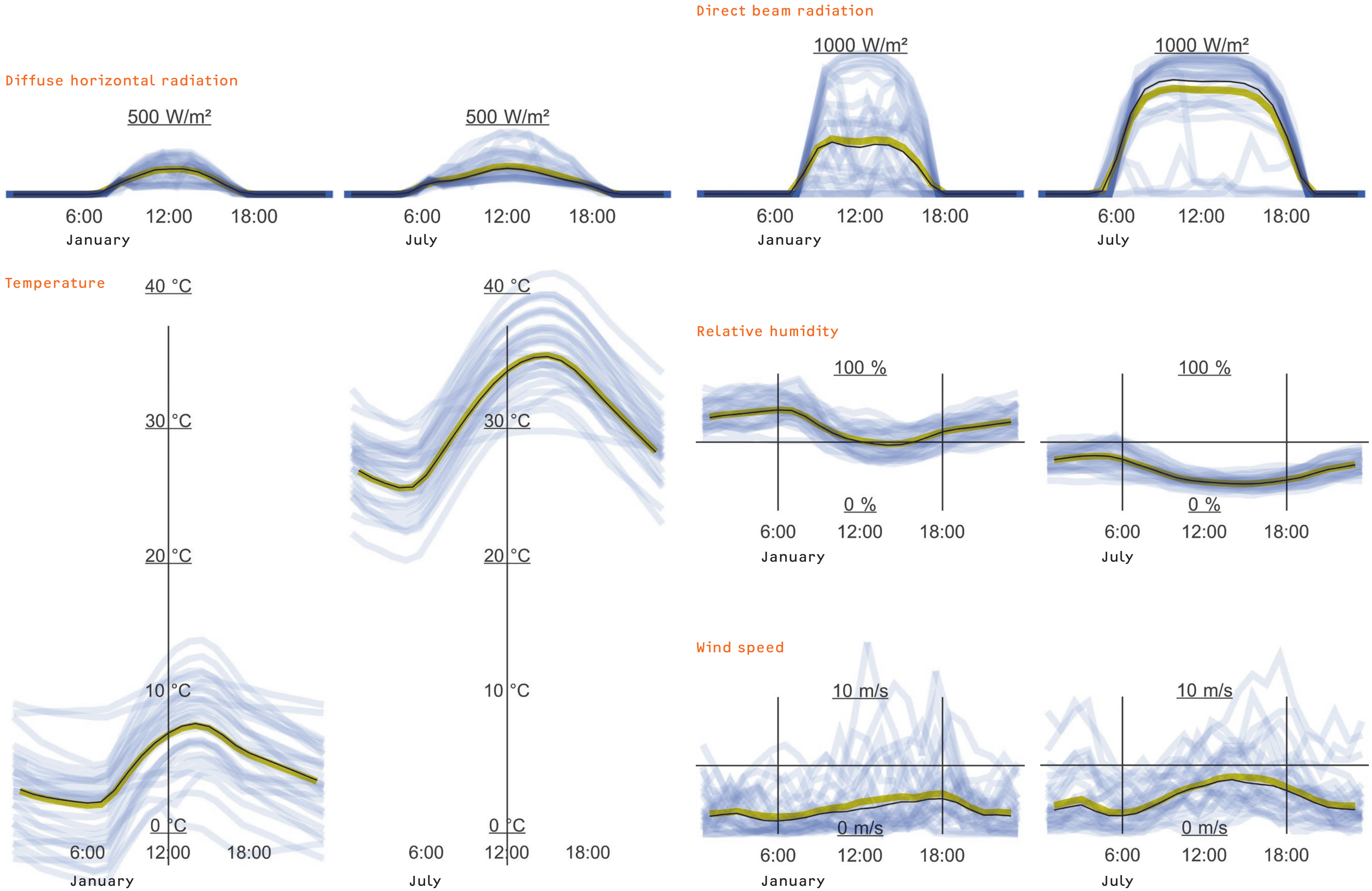


Fig. 319: Comparison of SOLARCHVISION plots with the average (yellow) and SOLARCHVISION standard average (black) for different climatic factors (Meteonorm 6.0 TMY file for Tehran)

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available at http://weather.whiteboxtechnologies.com

U.S. Department of Energy:
Typical Meteorological Year in EnergyPlus weather format (.epw) including hourly solar radiation and temperature data, etc. Over 1,000 stations are available at: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm, based on 20 sources including :
{
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ISHRAE: Indian Society of Heating, Refrigerating and Air-Conditioning Engineers
IWEC: International Weather for Energy Calculations
ITMY: Iranian Typical Meteorological Year
CTZ2: California Climate Zones 2
CWEC: Canadian Weather for Energy Calculations
CIBSE: Chartered Institution of Building Services Engineers
CityUHK: City University of Hong Kong
CSWD: Chinese Standard Weather Data
CTYW: Chinese Typical Year Weather
ETMY: Egyptian Typical Meteorological Year
IGDG: Italian Climatic data collection “Gianni De Giorgio”
IMGW: Instytutu Meteorologii i Gospodarki Wodnej
INETI: Synthetic data for Portugal
NIWA: New Zealand Data from NIWA
RMY: Australia Representative Meteorological Years
SWEC: Spanish Weather for Energy Calculations
TMY: Typical Meteorological Year
}
for detailed information about each of these resources please visit: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_sources.cfm

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About the Authors

Mojtaba Samimi was born in 1980. He entered NODET's Allameh Helli School in Tehran in 1991, where he basically focused on the science of geometry as well as computer programming. He started his studies of architecture at the School of Architecture and Urban Planning at Shahid Beheshti University in Tehran in 1999. At that time, students were prohibited to use computers for design processes; nevertheless, he continued developing programs parallel to investing time in architectural and technical drawing.

From 2004 and 2007, parallel to his academic studies in architecture, Mojtaba worked on the design and modeling of architectural projects with a small team of architects in Bonsar. As a result of the outstanding team work between all members, including Mohammad Majidi, Kaveh Rashidzadeh, Hamed Khosravi and others, the practice completed a number of projects and was awarded first prize in Iran's Grand Prix of Architecture in 2005 for one of the successfully completed schemes.

The objective of Mojtaba's Master thesis, titled "From the Sun to the Architect", was the development of a practical design method to integrate the active and passive aspects of the sun in planning buildings. His achievements were honored with two national awards: the best Master degree dissertation in the field of architecture in 2007 and, in 2008, the Khwarizmi Young Award in the category of applied research.

Apart from working on the architectural design and structural coordination of different building types, he has focused mainly on providing services as a solar-climatic analyst/consultant and developing the SOLARCHVISION research program in his studio titled Raz-Mehr-Mehraz. During his career, he has collaborated on the development of a number of small and large architectural and urban planning projects in Iran and some other countries. Some of these projects were commissioned by professional firms, others were specific research projects which were carried through in collaboration with the research/technical departments at universities, with professors or graduate students.

In 2010, the Institute for Membrane and Shell Technology invited him to present his studies to a Master course at Anhalt University of Applied Sciences in Germany. In 2011, he received a scholarship from the German Academic Exchange Service (DAAD) to work as a senior research assistant at the Berlin Institute of Technology on the energy efficiency dimension of the Young Cities project.

Mojtaba has published a number of papers for international conferences and added contributions to books on optimization methods in architecture. Besides architecture, he spends time developing computational tools for advancing design modeling and analysis.

Dr.-Ing. 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 at the Technical University Berlin. 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 nine 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 associate professor at the Berlin University of Arts, where he will be representing the Chair of Building Services Engineering in the summer semester 2014 as a guest professor. He has also worked on several architectural projects, including the first zero-energy office building in Iran and, as an expert for energy efficiency, has been a member of the board of judges at international architectural competitions.

Universitätsverlag der TU Berlin
ISSN 2193-6099 (Print) ISBN 978-3-7983-2675-0 (Print)
ISSN 2193-6102 (Online) ISBN 978-3-7983-2676-7 (Online)

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Road, Housing & Urban Development Research Center
ISBN 978-600-113-113-4