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An approach for developing sensitive design parameter guidelines to reduce the energy requirements of low-rise apartment buildings

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ABSTRACT

High levels of energy consumption in residential buildings and global warming are important issues. Thus the energy performance of buildings should be improved in the early stages of design. This article describes an approach for developing guidelines on sensitive and robust design parameters for the present, the 2020s, the 2050s and the 2080s. Such guidelines can help architects to design low-rise apartment buildings that require less energy for various purposes, such as heating or cooling. The article consists of a general literature review, interviews with architects, the generation of case-specific information and a mock-up presentation and a meeting with professionals. An example guideline that aims to reduce annual cooling energy loads under global warming in low-rise apartment buildings located in hot-humid climates is presented to demonstrate how the proposed approach can be applied. For this guideline, case-specific information was generated, and a global sensitivity analysis based on Monte Carlo Analysis and the Latin Hypercube Sampling technique was performed. The results show that the suggested approach is feasible and could be used to provide helpful information to architects during the design of low-rise apartment buildings with high energy performance. The most sensitive design parameters that affect annual cooling energy loads in low-rise apartment buildings were natural ventilation, window area, and the solar heat-gain coefficient (SHGC) of the glazing. The results are relevant for the present, the 2020s, the 2050s and the 2080s.

1. Introduction

Increasing energy demands and decreasing energy availability throughout the world are leading to the compulsory efficient usage of energy in every sector. One of the main sectors of high energy consumption is buildings. Thus, the design process and the energy performance of buildings are critical issues for designers [1].

Designing buildings to have high levels of energy performance is a complex and iterative process because building performance evaluations are difficult and can require a multiplicity of views and tools. Performance evaluations are mostly applied for complex buildings, such as office buildings, which are to be considered for certifications, such as LEED. However, evaluations are usually applied in the late stages of design because architects do not often have experience with performance evaluations or understand the importance of energy simulation tools for this purpose. In addition, the design teams for complex buildings consist of a diverse array of professionals, including building services engineers, building physics consultants and project managers. However, for small projects, such as low-rise apartment buildings, design teams rarely include energy performance professionals. Therefore, performance evaluations for small buildings are rarely applied, and each team member, especially the architect, makes design decisions according to individual professional views [2]. Architects have general knowledge about form, materials, and preferred HVAC systems in buildings. If the impacts of these factors on energy performance are known by architects, then this knowledge can be used to improve energy performance during the early stages of design [3]. Consequently, the early design process for small projects should be collaboratively supported by different approaches, such as building energy simulation tools, additional professionals, and paper-based documents, because decisions made in the early design stages can be based on incorrect and incomplete knowledge [4]. This possibility can lead to the construction of buildings that do not meet expected performance targets. In the late design process, a reduction in energy consumption is possible, but interventions are limited because many design decisions have already been made [5,6]. Therefore, interventions can also waste time and resources.

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One method to overcome this problem is to provide information to architects using paper-based documents, which can be grouped as special papers, guidelines, national codes and standards. These documents are significant tools for countries. The usefulness of information depends on two conditions: (1) the results of the scientific studies should be problem-oriented and accepted in the practical field [7], and (2) they should be understandable by professionals. However, statements in scientific and practical sources can differ. For instance, although the term ‘energy efficient buildings’ is regularly used by researchers, while the term ‘green buildings’ has the same meaning among professionals in Turkey. Several books related to improvements in the energy performance of buildings have been published, and they often contain detailed and complicated information. Therefore, guidelines that include specific and practical knowledge on the energy performance of low-rise apartment buildings in local climatic conditions and in cities could aid architects in designing energy-efficient buildings. Data from simulations could also play a beneficial role. In addition, because guidelines are helpful for spreading knowledge among professionals, they can prompt the integration of information into the practical design process.

This article proposes an approach for developing guidelines to identify sensitive and robust design parameters and thus reduce the energy consumed for different purposes in low-rise apartment buildings located in cities or climatic regions. An example guideline was developed by following the steps of the proposed methodology. The basic aim of the guideline is to provide information to architects about the impacts of several design parameters on annual cooling energy loads in low-rise apartment buildings located in a hot-humid climatic region of Turkey during the early stages of design.

2. Proposed approach to guideline development

In this section, the general approach to guideline development is discussed and explained in detail. The steps of approach are shown in Fig. 1.

In the first step, the aim, subject and scope of the guideline are determined based on the necessities and problems in a given climatic region or city. The subject should be narrow and case-specific because several sources for general issues and climatic conditions probably exist in the literature. Next, existing studies related to the determined subject are reviewed. During the literature review [8], sources such as books, articles, journals and guidelines that can provide relevant information about various methods and similar studies are collected and summarized.

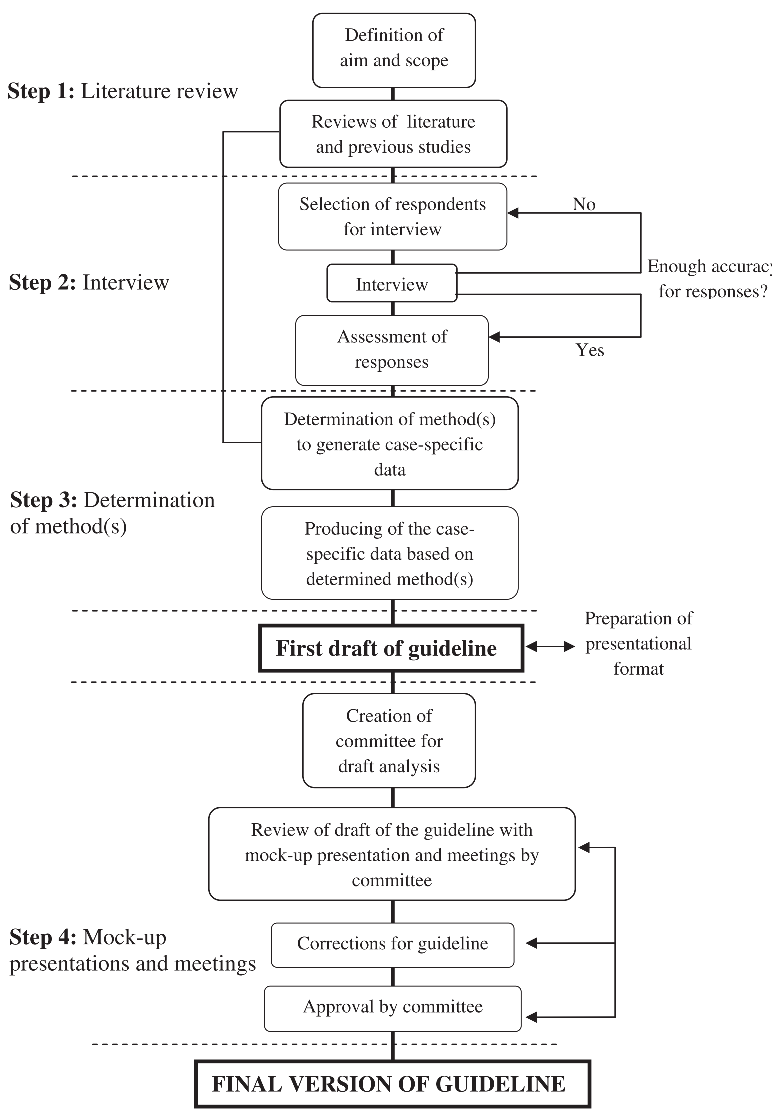

Fig. 1. Schematic diagram of the proposed approach.

In the second step, interviews are conducted. Interviews are preferred because the amount of reliable data on the preparation of guidelines is limited. In addition, interviews are important because they help to gather information on specific topics to be researched and the audience of the guideline. In addition, interviews can easily determine the audience's needs, considerations and perceptions about the specific topic. Interviews can be structured or unstructured, depending on the case-specific subject. One of the important points for this process is to determine the identity and number of participants. Participants should be selected among architects who have experience about case-specific subject for a given city or climatic region because guidelines are mostly used by architects who do not have a sufficient background in a given subject and are working in the same city or climatic region. Another significant point is that it is necessary to evaluate accuracy of collected data from participants before analyzing them. If they have enough accuracy, the next step can start. If not this process should be repeated.

In the third step, methods for producing case-specific guideline information are selected. First, general information that is essential to the guideline is collected from the literature review. To generate case-specific data, different methods are preferred, depending on the results of previous steps and the case-specific subject. Simulation programs are an important tool for such processes as the calculation of energy demands for heating, cooling, lighting, and ventilation because they are powerful and can accurately model various systems. In addition, several design alternatives can be modeled in a limited amount of time. However, most simulation programs are not commonly used by designers, architects or engineers because individual users may not have enough skill, background or time to use such tools during the design process [9]. Therefore, simulation programs can be used by professionals to produce general information and analyze the influence of design parameters using different methods. For example, appropriate statistical methods, such as linear or nonlinear regression models and stepwise regression, can be used to analyze the relative impacts of design parameters [10]. Furthermore, sensitivity analyses can be used to find sensitive and robust design parameters that affect case-specific outputs. Sensitivity analyses can be grouped into screening, local sensitivity, and global sensitivity methods. Screening methods are usually preferred for a large number of design parameters. Local sensitivity methods are based on variations of only one design parameter. Global sensitivity methods investigate the impacts of all design parameters simultaneously [11,12]. Several mathematical methods have been developed for sensitivity analyses [13,14]. One of the advantages of sensitivity analysis is that although limited design alternatives are analyzed for a single case study using a deterministic approach, multiple design alternatives can be evaluated probabilistically, and design parameters are described based on existing construction possibilities using a probability density function in the sensitivity analysis. However, construction technologies change over time. For example, high-performance glazing with a low solar heat-gain coefficient (SHGC) can be developed. Therefore, guidelines for such a material will not be valid in the future. To prevent this situation, guidelines should be updated regularly based on technological advancements. After determining a suitable method, case-specific information is generated, and a first draft of the guideline is developed.

In the last step, mock-up presentations and meetings with specialists are conducted. After developing the first draft of the guideline, the mock-up presentations and meetings are conducted. The specialist feedback gathered in this process is helpful when writing the final draft and in specifying the final scope, quality and validity of the guideline. Specialists should be experts from different disciplines and have experience and studies with the case-specific subject. These specialists can evaluate and substantially improve the first draft of the guideline. The required number of mock-up presentations and meetings are depend on the complexity of the subject. In addition, individual meetings can be held with specialists, as needed.

3. Application of the proposed approach in the development of an example guideline

3.1. Definition of aim and scope and literature review

In this guideline, cooling was selected as the specific subject for low-rise apartment buildings in a hot-humid climate in Turkey because annual cooling energy loads are usually higher than heating energy loads in this region. In addition, annual cooling energy loads are expected to increase, depending on the magnitude of global warming [15]. Therefore, the impacts of climate change were taken into account. The city of Izmir, the third largest city in Turkey, was chosen because it is in a hot-humid climatic region. The aim of the guideline is to support architects during the design process to reduce the cooling demand of low-rise apartment buildings in Izmir. The guideline indicates the relative impacts of selected design parameters on annual cooling energy loads for the present, the 2020s, the 2050s and the 2080s.

Designing low-rise apartment buildings in hot-humid climatic regions of Turkey based on the developed guideline can reduce the amount of energy consumed for cooling compared to similar buildings designed based on the minimum requirements in TS 825-Thermal Insulation Regulation in Buildings, which is a standard for reduce energy consumption in Turkey [16]. The developed guideline does not contain other measures for energy efficiency issues, such as heating, lighting, water usage and hot water requirements. In addition, the information in the guideline cannot be applied to all climatic conditions or types of buildings. In design stage of buildings, collaboration with different professionals (mechanical engineer, electrical engineer, etc.) is very important to improve energy performance.

Existing studies were reviewed to provide general information about the design parameters that affect cooling energy loads, and similar guidelines were reviewed to investigate the ways in which they were prepared. Several of the outstanding guidelines are summarized below.

ASHRAE GreenGuide: The Design, Construction, and Operation of Sustainable Buildings was published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [17]. It focuses on the technical aspects of high-performance building design, teamwork and close coordination between professionals. Thus, this guide is mainly used by engineers. The ASHRAE Advanced Energy Design Guide [18] is another important guideline that consists of a series of guidelines, including several recommendations to save energy beyond the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1. Both sets of guidelines were developed for small hospitals and healthcare facilities, highway lodging, small warehouses and self-storage buildings, K-12 school buildings, small retail buildings and small office buildings. ASHRAE also published a new guideline in 2011 for small to medium office buildings and K-12 school buildings to achieve 50% energy savings beyond the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 [19]. The most important feature of these guidelines is the different recommendations for the eight climate zones of the United States. The ASHRAE Advanced Energy Design Guides were prepared by a committee of professionals and practitioners. Members from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the American Institute of Architects, the Illuminating Engineering Society of North America, the US Green Building Council, and the US Department of Energy guided and supported the preparation of the guidelines. In addition, all recommendations in the guidelines were tested with hourly energy analysis software. Thus, building energy analysis programs can be used to prepare guidelines. Guide A: Environmental Design [20] is a guideline developed by The Chartered Institution of Building Services Engineers (CIBSE), an institution that generates different guidance and codes related to the improvement of building performance. This guide is a reference for low-energy sustainable building design, and its primary focus is to provide assistance during the design, installation, commission, operation and maintenance of buildings. The Multifamily Green Building Guidelines [21] were produced by Green Building in Alameda County and Build It Green. This series of guidelines provides cost-effective recommendations to minimize construction-related waste and to reduce operating costs. In addition, this guide contains methods for reducing the impacts of buildings on the environment in California communities. As a result, most guidelines contain general information about energy efficient building designs. One significant feature of the approach proposed in this study is its focus on guidelines that identify the impacts of design parameters on energy demands, such as cooling. Thus, the guideline can be used directly by architects during the design process of buildings located in a region or city.

3.2. Interviews

The interviews were conducted in the spring of 2010 to determine the opinions of architects working in Izmir on the following four topics:

- Energy for heating or cooling, which is mostly needed in apartment buildings under considerations of global warming.
- Architectural measures to reduce energy consumption for cooling in apartment buildings.
- Information used to develop architectural measures and integrate them into the design process to reduce energy consumption for cooling in apartment buildings; and
- The sources used to obtain relevant information (e.g., books, journals and the internet).

Another objective of the interviews was to obtain general feedback on the guideline. Therefore, at the end of each interview, interviewees were asked to comment on what they consider to be necessary for a guideline related to reducing energy consumption for cooling in low-rise apartment buildings in Izmir. The respondents consisted of five architects who have worked on commercial architectural projects in Izmir and are considered to be experts on energy efficiency in buildings. The sample size was satisfactory because the number of architects in Izmir who are experts on this subject is limited. Further, as the number of respondents increases, the data become similar. The importance of building energy performance related to cooling requirements is a new issue among professionals in Izmir, and they lack information on the subject. The interviews were categorized as qualitative and semi-structured and were performed in person. The responses shown here are limited to issues related to the four topics. The five interviewees are coded as A–E.

3.2.1. Responses for topic 1

No common perception among the interviewees about heating and cooling energy loads was found, but a portion of the interviewees agreed that cooling requirements were greater than or equal to heating requirements. Only one interviewee considered heating loads to be greater than cooling requirements. The general perception of global warming was that the temperature would be greater in the future. The respondents made the following observations:

- Cooling loads are greater than heating loads in Izmir (A).
- The heating and cooling requirements are approximately equal, but the number of heating degree days (HDD) is less than the number of cooling degree days (CDD). In addition, cooling is as an emerging occupancy comfort demand (B).
- Although cooling requirements are greater than heating requirements, the difference between heating and cooling demands is minimal (C).
- Cooling loads are greater than heating loads, and cooling is a major problem in apartment buildings because individual measures can be taken to protect against the negative impacts of low temperatures in winter. However, the number of individual measures that can be taken to protect against the negative impacts of high temperatures are limited during the summer (D).
- Heating demands are higher than cooling demands. Furthermore, cooling for comfort is a new expectation by owners in apartment buildings (E).

3.2.2. Responses for topic 2

Most interviewees stated that orientation, thermal insulation and materials are common measures to reduce cooling requirements. However, all interviewees acknowledged that the orientation of residential buildings can rarely be chosen, due to the high population density, especially in the city center.

- Shading, orientation and insulation are important measures, but architects usually do not prefer shading devices that do not add esthetic advantages to a building. Moreover, the use of plants, natural ventilation and wind catchers can reduce cooling loads in residential buildings (A).
- Reaping benefits from orientation in the city center is difficult, but shading devices and insulation are helpful. Furthermore, although natural ventilation is an effective measure for cooling, the configuration of windows is not an easy problem in residential buildings. The appropriate choice of materials is another important measure that is easily applicable (B).
- Insulation is necessary to reduce both heating and cooling demands in residential buildings. Therefore, Thermal Insulation Regulations in Buildings [16] should be known by architects, but these regulations are not easily understandable. The use of appropriate materials is an important measure for cooling in residential buildings (C).
- Wind direction should be considered during the design process, and shading devices and thermal insulation are significant factors that help to reduce cooling demands (D).
- Orientation is the most important measure for cooling. Material selection, especially the use of ecological materials, is another effective measure. In addition, space organization helps to decrease cooling loads (E).

3.2.3. Responses for topic 3

All respondents agreed that local climatic data and information concerning materials are needed.

3.2.4. Responses for topic 4

The interviewees believed that the necessary information could be obtained primarily from the internet, journals, magazines and seminars organized by different institutions.

- General information is accessible from the internet, journals and seminars. Experience was also considered to be important,

and it was stated that undergraduate courses are still useful in professional life (A).
- Most knowledge can be garnered from the internet, material catalogs and journals (B).
- Seminars on thermal insulation organized by the Chamber of Architects and journals are sources for information. Today, search engines are also an easy way to access knowledge (C).
- Cooperating with mechanical engineers is an effective way to collect necessary information. Seminars organized by the Chamber of Architects are helpful. Sectoral trade fairs and journals provide access to knowledge (D).
- Magazines and the internet also provide access to information (E).

Another subject of discussion was the guideline. All interviewees answered that the guideline can be helpful and should cover local climatic data. These climatic data should be explained with graphics that are easy to understand. In addition, the general belief among the interviewees was that shapes and complementary texts to express information in the guideline could improve the texts' intelligibility. A number of interesting conclusions resulted from the interviews:

- Cooling in apartment buildings is a new requirement for comfort.
- Constructing a building in the appropriate orientation increases energy performance, but this strategy is usually not possible in dense cities.
- Thermal insulation is a well-known measure to increase energy performance. Other measures related to color usage, glazing selection, thermostat temperature, air infiltration, and their impacts on cooling consumption were not emphasized or mentioned by the interviewees.
- Major sources of information are web-based documents and journals. Books were not mentioned by the interviewees.

3.3. Determination of methods to provide case-specific data for the guideline

Global sensitivity analysis was selected as the main method to produce case-specific information. Sensitivity analyses can be used to determine the relative impact of design parameters on annual cooling energy loads. In this study, the Monte Carlo Method (MCA) with Latin Hypercube Sampling (LHS) was used because it is a common technique that is useful for building thermal simulations and can be performed with a minimum number of simulations [22–24]. Further information about sensitivity analysis, MCA and LHS can be found in [25–29]. The general steps [24] for applying global sensitivity analyses to a model are summarized below.

3.3.1. Determination of output

In this study, the annual energy rate for cooling was a case-specific subject for the guideline. Therefore, the annual cooling energy load was taken as an output.

3.3.2. Determination of inputs

Eight parameters were considered to be the main building design parameters that can be easily controlled by architects during the design process in low-rise apartment buildings: building shape, window to external wall area, thermophysical properties of building materials, insulation, air infiltration, natural ventilation (during the day), envelope color and zone height. Thirty-three detailed building design parameters were derived from the main design parameters (Table 1).

Table 1
Building parameters, their probability density functions and ranges.

Building parameters	Unit	Min. value	Max. value
Length of building	m	12	22
Width of building	m	12	22
Air infiltration rate (air infilt.)	ach	0.5	2
Natural ventilation rate (natural vent.)	ach	0.5	4
Windows area: south	%	5	90
Windows area: north	%	5	90
Windows area: east	%	5	90
Windows area: west	%	5	90
U-value of window-South (*U* value: window-south)	$W/m^2 K$	1.1	2.9
U-value of window-North (*U* value: window-north)	$W/m^2 K$	1.1	2.9
U-value of window-East (*U* value: window-east)	$W/m^2 K$	1.1	2.9
U-value of window-West (*U* value: window-west)	$W/m^2 K$	1.1	2.9
SHGC of window-South	–	0.28	0.75
SHGC of window-North	–	0.28	0.75
SHGC of window-East	–	0.28	0.75
SHGC of window-West	–	0.28	0.75
Color of external walls-South (color: ext. wall-south)	–	0.1	0.9
Color of external walls-North (color: ext. wall-north)	–	0.1	0.9
Color of external walls-East (color: ext. wall-east)	–	0.1	0.9
Color of external walls-West (color: ext. wall-west)	–	0.1	0.9
Color of roof (color: roof)	–	0.1	0.9
Space height	m	2.6	3
Specific heat of external wall	J/kg K	800	990
Thickness of thermal insulation on external walls-South (thickness: ins-ext. wall-south)	m	0.01	0.2
Thickness of thermal insulation on external walls-North (thickness: ins-ext. wall-north)	m	0.01	0.2
Thickness of thermal insulation on external walls-East (thickness: ins-ext. wall-east)	m	0.01	0.2
Thickness of thermal insulation on external walls-West (thickness: ins-ext. wall-west)	m	0.01	0.2
Thickness of thermal insulation on roof (thickness: ins-roof)	m	0.01	0.2
Thickness of thermal insulation on ground (thickness: ins-ground)	m	0.01	0.2
Thermal conductivity of external wall (thermal conduct.:ext. wall)	W/m K	0.15	2.1
Thermal conductivity of thermal insulation on external wall (thermal conduct.:ext. wall ins.)	W/m K	0.028	0.052
Thermal conductivity of thermal insulation on roof (thermal conduct.: roof ins.)	W/m K	0.028	0.052
Thermal conductivity of thermal insulation on ground (thermal conduct.: ground ins.)	W/m K	0.028	0.052

3.3.3. Assignment of probability density function to each input and generation of input matrix

This step, which consists of two substeps, is important because probability density functions can affect the results of a sensitivity analysis. In the first substep, the appropriate probability density functions were assigned to the 33 derived building design parameters. The probability density function was considered to be continuous and uniform for all parameters in Table 1. In this probability function, all values have the same likelihood of occurring [23]. Minimum and maximum values are essential to define building design parameters according to a continuous, uniform possibility density function. Therefore, minimum and maximum values for each parameter were determined according to current possibilities, commonly used materials in the construction industry and regulations in Turkey. For example, EPS, XPS, glass and rock wool are common insulation materials used in Turkey. These materials were defined according to their thermal conductivities. The rock wool is the minimum thermal conductivity, and the EPS is the maximum thermal conductivity. Thus, the minimum and maximum values of thermal conductivity for the insulation parameters were based on these values, and architects in Turkey can only choose among building design parameters with the values that are shown in Table 1.

In the second substep, a sample matrix is created. Four hundred samples for each building design parameter, depending on the continuous uniform density function, were generated randomly using the program SIMLAB 2.2. SIMLAB is a free and common tool for Monte Carlo-based sensitivity analyses [30]. The number of simulations to obtain enough level of accuracy is important. According to some publications, the minimum number of samples should be more than 60–80 [14,31]. Therefore, the number of simulations was taken as 400 to ensure accuracy in the sensitivity analysis. A matrix was subsequently assembled based on the LHS method.

3.3.4. Weather data

Izmir is located on the Aegean Sea coast of Turkey (38°25′ North latitude and 27°09′ East longitude), and Izmir's climate can be classified as a hot-humid climate. The winter season is warm, and the summer season is hot and humid. The mean annual temperature is approximately 16.08 °C. The minimum average temperature usually occurs in January, (5.7 °C), and the maximum mean temperature occurs in July (33 °C). The annual mean relative humidity is approximately 64.58%.

Building energy analysis tools make dynamic, time-dependent calculations and require hourly climatic data. Thus, the Typical Meteorological Year 2 (TMY2) for Izmir was used in this study. Instant climatic data are not preferred because they only show climatic conditions for a selected time period, such as 2011 for Izmir. However, TMY represents long-term climatic conditions of Izmir because it consists of a collection of monthly weather series for different years [32]. In addition, TMY is commonly used to evaluate the energy performance of buildings [33].

To evaluate the impact of global warming on design parameters, hourly climatic data for the future is necessary. Three different climatic data sets for Izmir were developed using the UK Handley Center's third generation coupled atmosphere–ocean global climate model (HadCM3). This model enables investigations of the rate of climate change and the associated impacts [34]. This model is composed of various projections that are based on predicted future gas emissions. The A2 scenario was used for this study because appropriate data were obtained from data based on the A2 scenario. The main concept of this scenario is a heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other scenarios [35]. The projections for Izmir were made based on the averaged results of A2a, A2b and A2c experiments for the four grid points closest to the city. These points provide hourly weather data for the 30-year time periods of the 2020s (2011–2040), the 2050s (2041–2070) and the 2080s (2071–2100). All weather data files were generated based on a 'morphing' approach using The Climate Change Weather File Generator (CCWorldWeatherGen) [36], which is a tool that generates climate change weather files in different locations for use in building energy analysis programs. The morphing approach is a combination of current weather data and the results of climate change models. This approach has three advantages: the weather series used as a baseline climate are reliable; the final weather sequence is meteorologically consistent; and spatial downscaling is achieved based on current weather information, which is generated for actual locations [33]. Fig. 2 shows the monthly mean temperature, relative humidity and direct solar radiation for Izmir used in all simulations for the aforementioned time periods. While the annual mean temperature and daily solar radiation both increase, the relative humidity decreases over time. Accordingly, the annual mean temperature would increase by approximately 4 °C, the solar radiation would increase by only 5% and the relative humidity would decrease by 10% by the 2080s in Izmir.

3.3.5. Calculation of outputs

This study analyzed low-rise apartment buildings. Thus, as a generic example in Izmir, an existing low-rise apartment building (Fig. 3) was selected to represent the general plan schema and architectural features commonly applied in Izmir.

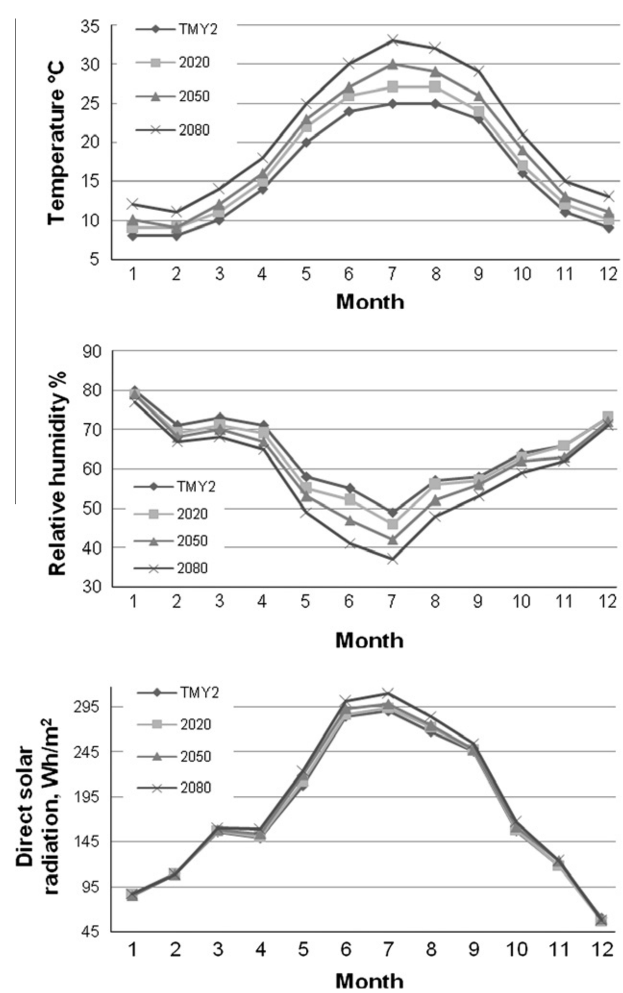

Fig. 2. Monthly temperature, relative humidity and direct solar radiation for the time periods of present, 2020s, 2050s, and 2080s in Izmir.

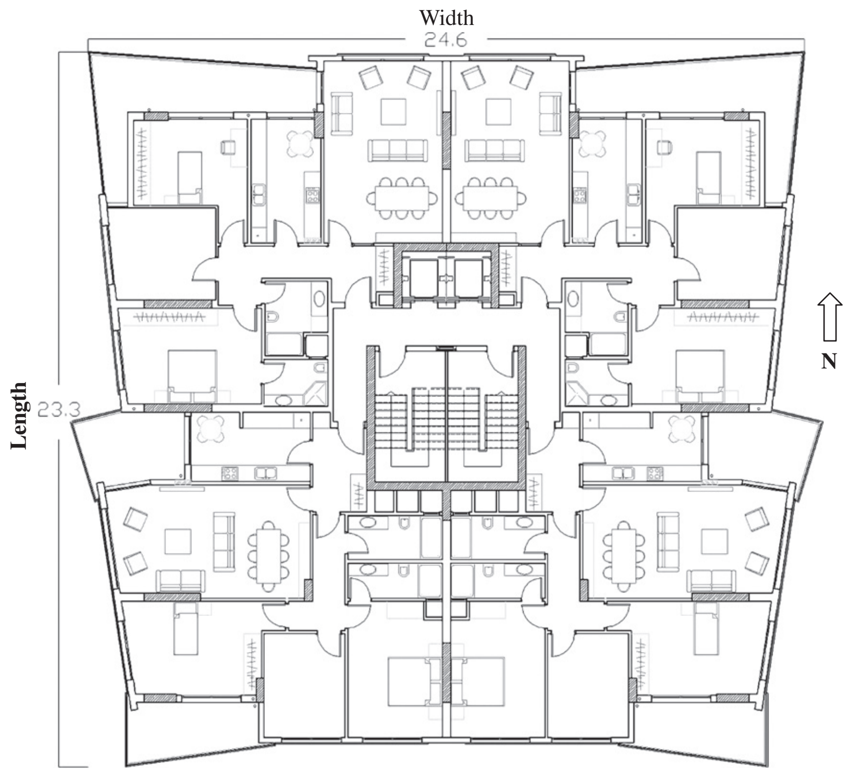

Fig. 3. Typical floor plan of selected low-rise apartment building.

The building has nine stories, a floor area of 4680 m^2, is well-insulated and fulfills all minimum conditions defined in TS 825-Thermal Insulation Regulation in Buildings [16] in Turkey. The major parameters of the thermal model are shown in Table 2.

The average annual heating energy load of existing low-rise apartment buildings is 22.3 kW h/m^2, while the average annual cooling energy load is 37.4 kW h/m^2. Simulation results for the 2020s, 2050s, and 2080s indicate an increasing trend in annual cooling energy loads and a reduction in heating requirements in existing low-rise apartment buildings in Izmir. Therefore, the high differences between annual heating and cooling energy loads may be due to future global warming, and the annual cooling energy loads could be more than 2.5 times the annual heating loads in the 2020s, 4.5 times the heating loads in the 2050s, and 7 times the heating loads in the 2080s.

Outputs corresponding to the generated sample matrix were calculated with the EnergyPlus 5.0.0 energy analysis software [37]. Approximately 400 EnergyPlus input files (IDF) for existing low-rise apartment building were created using Excel VBA 2007. In this study, the EnergyPlus program was used because it has been validated, is free and uses txt files as input and output files. In the thermal model, each story consists of two main zones. Zone 1 is the core of the floor covering the staircase, which is modeled as an unoccupied zone. Zone 2 is the remainder of the floor, including all flats. IDF files were used to calculate outputs for each climatic dataset representing the present, the 2020s, the 2050s, and the 2080s. Excel VBA 2007 was again used to evaluate the output files from EnergyPlus.

Table 2
Definition of existing low-rise apartment building.

Parameters	Values
U-value for external wall	0.61
U-value for roof	0.44
U-value for ground floor	0.65
U-value for window	2.76 W/m^2 K
Solar heat gain coefficient for glazing	0.63
Cooling system	Air conditioner but it is assumed that it has a central cooling system because a general schedule representing all habits of users is not possible
Set point temperature for cooling	26 °C
Window to wall area	47%

3.3.6. Evaluation of the results

Indicators are necessary to evaluate the importance of all design parameters. Several indicators, such as the Pearson Product Moment Correlation Coefficient (PEAR), the Spearman Coefficient (SPEA), the Partial Correlation Coefficient (PCC), the Partial Rank Correlation Coefficient (PRCC), the Standardized Regression Coefficient (SRC), and the Standardized Rank Regression Coefficient (SRRC) have been developed [30]. They can be used if samples are generated with the LHS method. In this study, the Standardized Rank Regression Coefficient (SRRC) was selected to define the sensitivity of each design parameter because it allows the evaluation of models that have a nonlinear relationship between inputs and outputs [38]. In addition, a positive SRRC means that as the value of the building parameter increases, the value of the corresponding output simultaneously increases. A negative SRRC indicates that changes in the inputs and outputs tend to go in opposite directions [22].

The results of the sensitivity analysis for different time periods are shown in Fig. 4, which includes the most significant design parameters for annual cooling energy loads. The figure is used in the guideline because it can help architects to decide which design parameters are sensitive or robust, and it shows the effects of increasing or decreasing the values of the design parameters. Architects can determine optimal design strategies and focus on

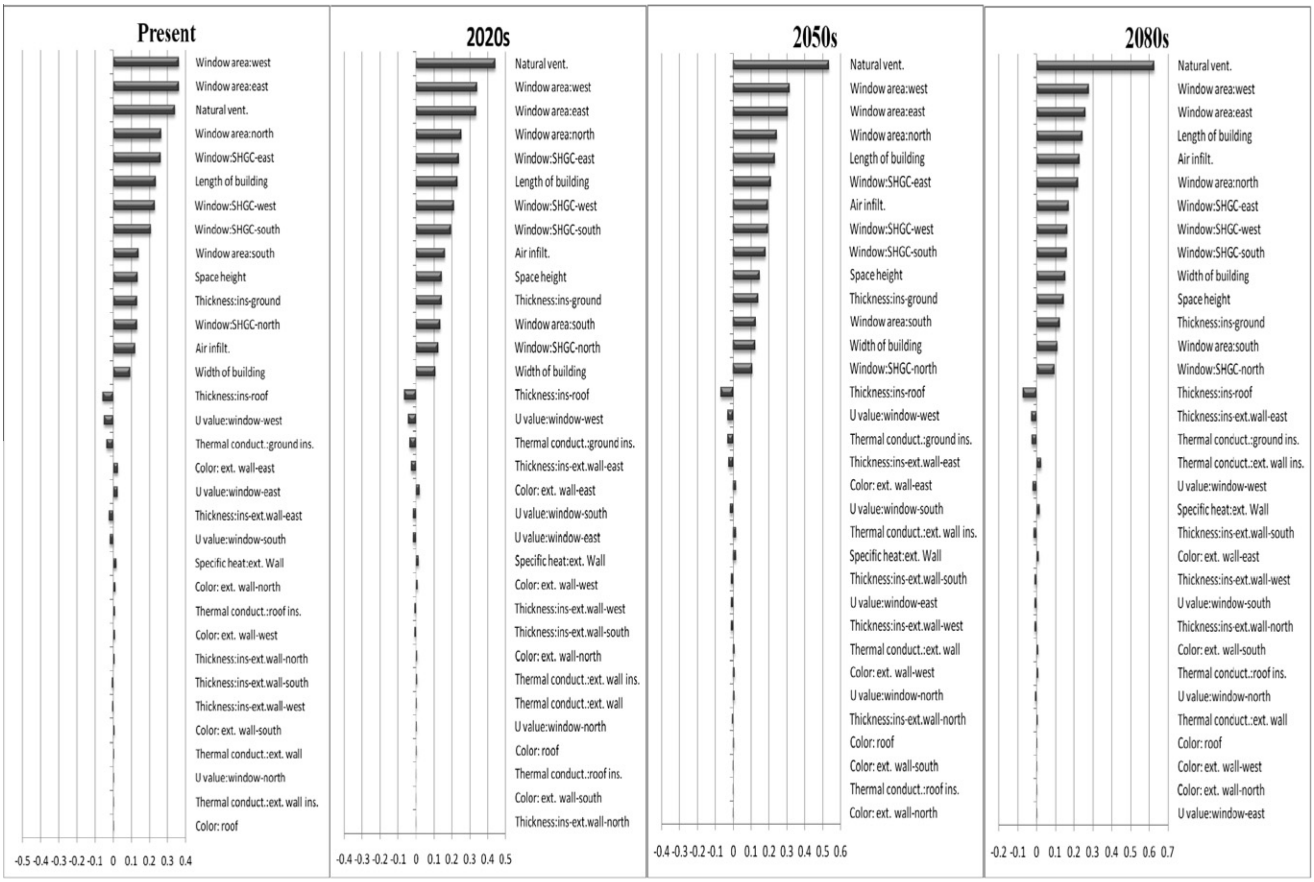

Fig. 4. The sensitivity of building design parameters in present, 2020s, 2050s, and 2080s.

sensitive parameters to reduce annual cooling energy loads and can use time efficiently.

In this study, design parameters with SRRC values greater than 0.1 were assumed to be the most important factors affecting annual cooling energy loads in low-rise apartment buildings. Other parameters were considered to be less significant. Based on this approach, fifteen parameters were identified as the most important for the aforementioned time periods: thickness: ins-ground, natural ventilation, window area: east, window area: west, window: SHGC-east, length of building, window area: north, window: SHGC-south, window: SHGC-west, window: SHGC-north, air infiltration, space height, window area: south and width of building. The most important design parameters were the same for all time periods, and only small differences in the order of importance of the parameters were observed. These changes were expected because the sensitivity of design parameters can change depending on climatic conditions. Furthermore, the window area, the solar heat-gain coefficient (SHGC) of the glazing and the ventilation (natural and air infiltration) are the major parameters that can be used to reduce a considerable portion of the annual cooling energy loads in low-rise apartment buildings during the design process. The most important results of the sensitivity analysis (Fig. 4) were summarized for use in the developed guideline. Architects using the guideline can also derive a greater number of results during the design process. However, outcomes cannot provide enough energy saving in low-rise apartment buildings located in different climates:

- Natural ventilation was the most important design parameter following window area in the east and west directions in the present period, and its importance increases in the 2020s, the 2050s, and the 2080s. Natural ventilation is a critical factor in the annual cooling energy loads of low-rise apartment buildings. If the natural ventilation rate is increased, especially when the outside temperature is higher than the inside temperature during the day, then the amount of energy consumed for cooling can increase. In these periods, natural ventilation rates should be reduced. However, night ventilation can help to reduce annual cooling energy loads because low temperatures at night decrease the amount of heat stored in a building. Therefore, the size and location of windows in plane and in section are significant design decisions. These factors should enable ventilation control during the day and night.
- Windows impact annual cooling energy loads in hot-humid climates. In general, a decrease in window area reduces annual cooling energy loads. East- and west-facing windows are more significant than south- and north-facing windows. East- and west-facing windows receive an excessive amount of solar radiation in the morning and afternoon in the summer. In addition, solar radiation arrives at low angles in the east- and west-facing windows. Therefore, controlling sun exposure is difficult in those orientations. Windows facing east and west can be smaller than south- and north-facing-windows to reduce annual cooling energy loads.
- Thermophysical properties of materials influence the energy performance of buildings. However, only glazings with low SHGC values provide significant energy reductions in annual cooling energy loads in hot-humid climates, and the glazings' importances vary, depending on orientation. Low SHGC values indicate that low solar radiation enters buildings from windows. In winter, low SHGC can increase heating demands. Thus optimum benefit should be considered. Solar radiation can also

be blocked by shading devices and combination of shading devices with glazings having high SHGC values can be helpful to reduce cooling loads but these devices are mostly beneficial on windows facing south. Thus, glazings with low SHGC values can be preferred for east- and west-facing windows, or the size of windows can be decreased. The *U* value of windows has a small impact on annual cooling energy loads and does not have a deterministic role in the climate under consideration. Glazing selections should be made according to the SHGC value in hot-humid climates. This value provides advantages that can easily reduce annual cooling energy loads, especially if the window area is large.

- Thermal insulation is the easiest and most cost-effective measure for energy conservation in buildings, but features of the climate and dominant energy demand should be taken into account when determining insulation thickness. Increasing the insulation thickness on external walls has a relatively small effect on annual cooling energy loads in hot-humid climates. Therefore, the insulation thickness for external walls should be determined based on annual heating demands and mandatory regulations. Increasing the insulation thickness should not be the first energy efficiency measure to reduce annual cooling energy loads. The most sensitive design parameters should be used to reduce annual cooling energy loads. Ground insulation has a relatively large influence on annual cooling energy loads compared to insulation on external walls, but an increase in the insulation thickness on the ground leads to more energy consumption for cooling because the ground surface is cooler than the above-ground space in summer as a result of the low soil temperature. A large insulation thickness can reduce heat losses from inside to the ground. The minimum ground insulation thickness specified in mandatory regulations is sufficient for cooling demand in hot-humid climates. Floor insulation is an essential measurement in multistory buildings because it can decrease negative impacts caused by other floors. Insulation is also more effective in the roof than in the external wall because the roof surface is exposed to high solar radiation during the day in the summer. The insulation thickness in the roof can be increased to reduce annual cooling energy loads in hot-humid climates.
- The infiltration in buildings is usually related to the quality of the construction process and the materials. The rate of infiltration affects annual cooling demand in buildings. As shown in Fig. 4, increasing the infiltration rate can lead to high cooling demands in buildings, due to the high outdoor temperatures in summer. The sensitivity of this parameter increases in the following years because the future mean outdoor temperature may be higher due to global warming. Thus, airtight buildings should be designed to reduce the uncontrolled flow of air. Airtightness is an effective design parameter to ensure low cooling requirements in buildings in hot-humid climates.
- Building shape can influence the benefits associated with local climatic conditions. Building length and width were considered in this study. In real situations, building shape is usually defined based on multiple factors. Building length had more impact than building width on annual cooling energy loads, and its importance increased over time. The building length was oriented from east to west, and this direction leads to high solar radiation in summer. However, control of the sun is not easy. The size of such facades should be less than the size of facades facing north and south, but this condition cannot be ensured every time. Therefore, when windows are placed on these facades, appropriate shading devices or glazing with low SHGC values should be used.
- Zone height directly affects the volume of the space and can change cooling demand. Floor height should be minimized for low cooling requirements, depending on architectural and technical necessities. In addition, the sensitivity of floor height was nearly the same in all time periods.
- A variety of external wall and insulation materials are used in the construction industry. In terms of cooling demand, external walls and insulation materials are not sensitive parameters in low-rise apartment buildings. Therefore, changing the insulation or external wall materials cannot significantly affect cooling requirements in low-rise apartment buildings in hot-humid climates. The sensitivity of these parameters was similar in the other time periods.
- The color of the building envelope minimally influences annual cooling energy loads, light-colored materials are suitable for external walls and roofs in hot-humid climates.
- Generally, one color is selected for all external walls, and every window has the same glazing. However, design decisions, such as the color, insulation thickness, thermophysical features of glazing, and window size should be specific to the orientation to benefit from design parameters in low-rise apartment buildings.

The first draft of the guideline, which covers essential outcomes, was generated at the end of this step. The scope of the chapters was determined according to the goals of the guideline and the results of interviews. The results are contained in various chapters of the first draft of the guideline. A brief summary of each chapter follows.

Chapter 1 introduces basic information about the audience, aim and content.

Chapter 2 provides general information on the climatic features of Izmir and the effects of global warming on cooling and heating energy loads.

Chapter 3 consists of general explanations for the design parameters that impact annual energy loads for cooling in buildings. In Chapters 2 and 3, information from the literature review is used.

Chapter 4 is the main component of the guideline. The effects of the selected design parameters on annual cooling energy loads are shown and are discussed.

3.3.7. Mock-up presentations and meetings

After developing the first draft guideline, several mock-up presentations and meetings with specialists on building energy efficiency were conducted to evaluate case-specific information and to create a final draft of the guideline. To begin this process, four academicians, including three architects and one mechanical engineer, were chosen. Next, a PowerPoint slide presentation was presented before completing the final draft. In addition, individual meetings were held with specialists. The results of the conversations and the presentation are summarized as follows:

- More graphs should be used in the guideline, and they should be clear and easily understandable for the audience. Explanations of the graphs are important and necessary.
- The language of the guideline should be based on daily practice.
- The guideline should not be excessively long. The guideline should directly present major information.
- The visual design of the guideline is essential, and design professionals should be consulted for this work.
- The guideline should not dictate a single, exact solution for low-rise apartment buildings because this approach can lead to the development of similar apartment buildings in a region and can limit the design freedom of architects. Architects should develop several solutions to reduce annual cooling energy loads.
- In brief, specialists thought the guideline would encourage architects in the design process.

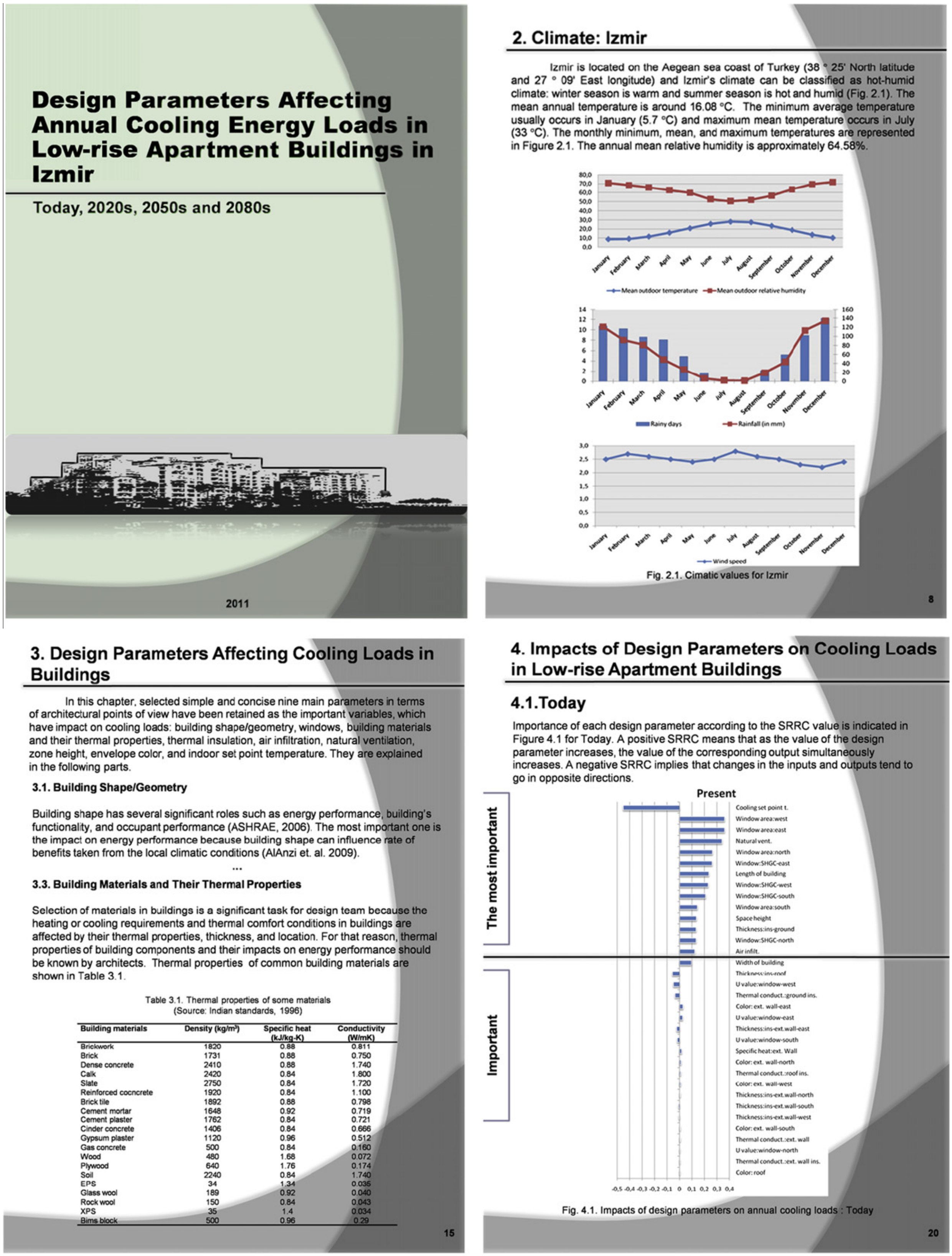

Fig. 5. Examples from the final version of the developed guideline.

According to the results of the meetings and presentation, the guideline was improved, and the final version was completed. The examples from the final version of the guideline are shown in Fig. 5.

4. Conclusions

This article presented an approach for developing a guideline to improve energy performance of low-rise apartment buildings by aiding architects during the early design process. The approach requires a comprehensive literature review; interviews with the main audience of the guideline; several simulation runs, depending on the selected method; and presentations and meetings with professionals. The following conclusions can be drawn: (1) this type of approach requires a significant amount of time to obtain extensive and reliable data, but it is feasible and easily applicable for a region or city; (2) the proposed global sensitivity analysis is helpful in developing a guideline to identify sensitive and robust design parameters; (3) this type of guideline provides necessary information for assessing the relevance and importance of design parameters; (4) building energy consumption can be reduced by using specific guidelines; and (5) global warming significantly influences the sensitivity of design parameters.

An example guideline was developed to illustrate the suggested approach, its functions and how it can be applied in a realistic case study. The guideline mainly identifies the impacts of building design parameters on annual cooling-energy loads for the present, the 2020s, the 2050s, and the 2080s in low-rise apartment buildings located in a hot-humid climate. According to the guideline, the most sensitive design parameters were natural ventilation, window area, and the solar heat-gain coefficient (SHGC) of the glazing.

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