1. Toolbox:

METHODOLOGY FOR THE IDENTIFICATION OF THE DETAILED SOLAR POTENTIAL OF URBAN AREAS

1.1. Description of the tool / methodology of the tool

The “Methodology for the Identification of the Detailed Solar Potential of Urban Areas” is a specific method developed by the Technical University of Madrid (UPM) with the aim of integrating the passive and active uses of solar energy at urban level and contributing to the reduction of CO_2 emissions in cities through the exploitation of their natural resources (the sun in this case). Cities are the most energy consuming areas; therefore, clean on-site energy generation should be a priority in climate protection strategies.

The methodology has been designed within the context of POLIS project and has been particularly applied to two urban areas of the Spanish city of Vitoria-Gasteiz of residential and industrial uses respectively. In this sense, a special emphasis has been given to guaranteeing full compatibility between local and national requirements related to solar energy use [1,2], as well as with the Geographical Information System (GIS) used by the City Council of Vitoria-Gasteiz [3] for urban related information.

The methology is summarised as follows:

1) Preparation of input data. A GIS cartography has to be used, which incorporates the information needed for the identification of the individual buildings constructive elements.
2) Passive solar potential assessment:
   - This phase begins with a local climate and micro-climate analysis with the objective to identify the so-called “underheated period” in which solar gains can contribute to the reduction of buildings heating needs.
   - The potential contribution of solar energy to buildings’ façade elements is then computed and shown out in specific maps, using a colour-based scale.
   - Recommendations for the passive design of buildings to optimise the passive solar contribution of the consolidated city and new urban areas also arise from this assessment.
3) Active solar potential assessment: a combined assessment of solar thermal and solar photovoltaic potential is carried out, where the supply of domestic hot water and heating needs is considered the first priority, and electricity production the second priority.
   - First of all, a basic structural analysis of available roof and façade constructive elements is carried out in order to determine their suitability for typical active solar components (PV modules / solar collectors).
   - The solar resource available on the constructive elements is then computed, using the acceptable losses categories specified by national requirements [2].
   - Solar thermal potential: Domestic hot water and heating needs are estimated for each building. Then the potential contribution of solar thermal systems to the previous needs is computed, where the solar collectors can be placed in roofs or façades. Results are shown in specific maps, using colour codes depending on the suitability of the constructive elements. For suitable elements, the nº of

collectors needed to cover a realistic percentage of domestic hot water and heating needs is also shown in the maps, which provides an indication of the different solar potential,
- Solar photovoltaic potential: After the assessment of roof and façade surfaces availability in terms of minimum size, use and structural characteristics, the solar potential is computed and shown in the maps using a colour-based scale.
- Recommendations for buildings location and shape and the design of constructive elements to optimise the active solar contribution also arise from this assessment, mostly useful for energy retrofitting of the consolidated city.

More details can be found in the following sections.

1.1.1. Preparation of input data

This phase begins with the detailed assessment of the buildings shape and typologies, with the aim of identifying homogeneous areas. As input data, a GIS cartography provided by the municipality of Vitoria-Gasteiz has been used. This cartography was completed with information of the Urban Development Plan [4] that is relevant for the solar potential assessment such as historical protected buildings, ordinances applicable in each urban plot, etc.:

- Information about Historical Protected Areas. The following assumptions were made:
  - Protected buildings are not be evaluated. These would require individual studies about the possibilities of integrating solar technologies respecting their protection status, which goes beyond the objectives of this Pilot Action.
  - Buildings surrounding protected buildings must be individually analyzed.
- Buildings structural information:
  - Buildings age has to be incorporated in the spatial database.
  - Structural classification is done based on legislation applicable at the year of construction and typical structural systems used. In the particular case of Vitoria-Gasteiz, 3 groups were defined according to the 3 legislations applicable: until 1988, from 1988 until 2006 and from 2006 on [5,6,7]
- Constructive elements identification:
  - Good quality 3D-CAD data of buildings is required in order to identify the different constructive elements where the solar potential will be assessed. To this aim, complementary use of aerial photographs can be useful.
  - These data are then imported to GIS maps, identifying each building construction element (roofs and façades) as independent units with the following associated information: dimensions, azimuth (orientation towards the south) and slope (relative to horizontal plane). This level of detail involves a larger amount of work compared with typical urban solar potential maps but provides very useful information for architects and municipal authorities in terms of realistic solar potential.

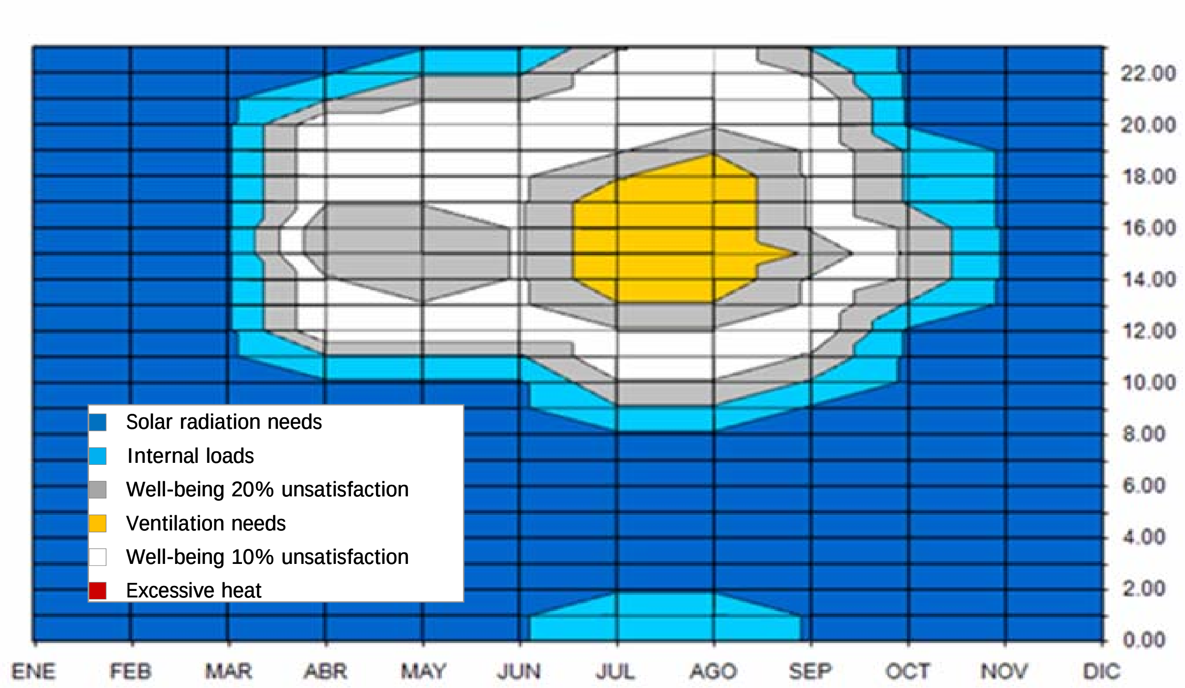
1.1.2. Passive solar potential assessment

Step 1. Climatic analysis

A detailed study has to be done of local climate and micro-climate conditions within the city, with the objective of identifying the so-called "underheated period" in which solar gains can contribute to the reduction of buildings heating needs:

– Givoni's diagram [8]: it establishes the relationship between outdoor climatic conditions and bioclimatic strategies applicable to buildings. From the analysis done the period October – March has been identified as the one in which the use of solar radiation for passive heating is prioritary: this is called the "under-heated period". It should be noted that this period is larger than the winter period, which is the traditional one usually considered in climatic analysis.

– Isolines diagram [9]: it is generated from hourly temperatures and allows identifying the hourly needs and strategies to obtain user comfort conditions. As shown in the following figure, the city of Vitoria-Gasteiz has high solar radiation needs throughout the year, especially in winter months. Also in more temperate months solar radiation would be very useful in the first daily hours, which could be obtained by a well-known bioclimatic strategy consisting of solar resource in day-time hours followed by accumulation in façades walls made of absorbing materials.



[Source: Software tool of the Construction and Architectural Technology Department (Departamento de Construcción y Tecnología Arquitectónicas), ETS Arquitectura – Technical University Madrid]

Figure 1. Isolines diagram of Vitoria-Gasteiz

From the climatic analysis done it can be concluded that all passive strategies typical of winter conditions should be taken into account in the under-heated months, which roughly correspond to 70% of the year. Amongst these, passive solar gain and consequent mechanisms of accumulation and night-time lag facilitate the improvement of thermal comfort inside residential buildings with important energy savings. The next figure summarises the recommended bioclimatic strategies for the city of Vitoria-Gasteiz.

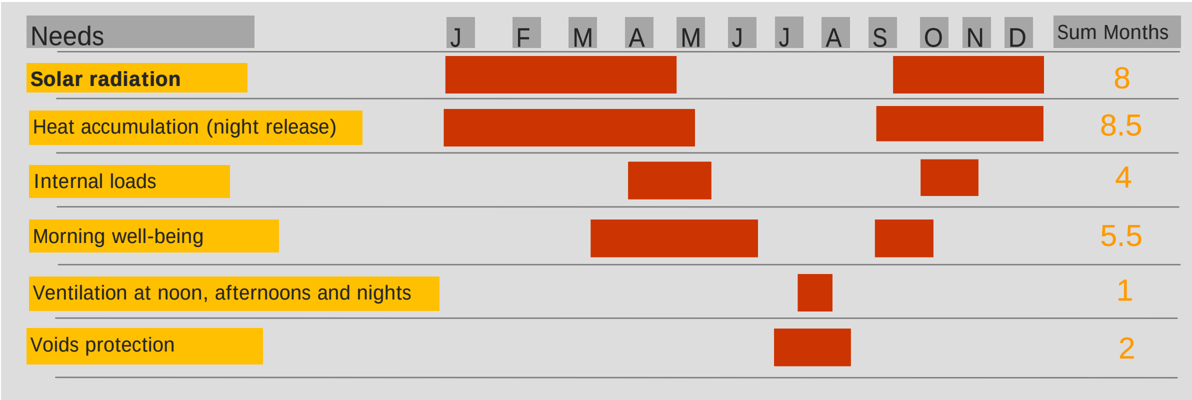


Figure 2. Summary of bioclimatic strategies recommended for Vitoria-Gasteiz

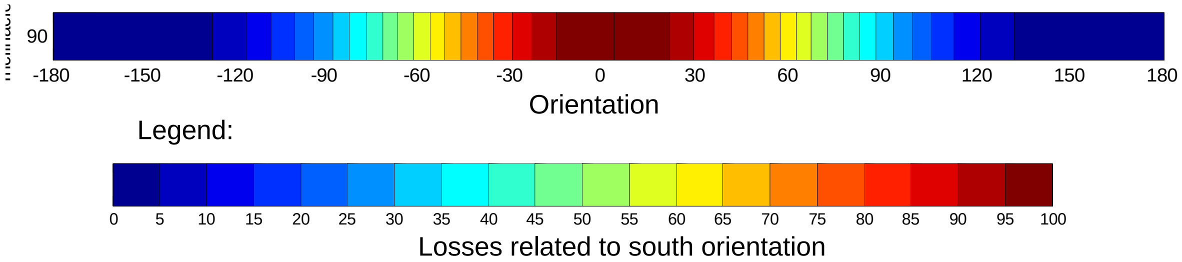
Step 2. Solar resource assessment

Traditionally, it has been considered that the minimum number of hours that the sun must fall on a façade is 2 in the winter solstice (21st December): this requirement is present, indeed, in many urban planning documents. In this methodology, based on the climatic analysis done of Vitoria-Gasteiz, the recommended criterion has been modified as follows. First of all, the time of analysis has been extended to the “under-heated” period (October-March); secondly, four hours centered on the solar noon have been considered due to the fact that in this period the most part of solar daily contribution occurs.

The solar resource assesment has been carried out using a software tool developed by the Instituto de Energía Solar of the Technical University of Madrid (UPM-IES), which besides solar radiation calculations also incorporates shadowing analysis[a] [10]:

- To this aim, direct solar radiation incident on building façades has been computed due to the fact than this is the effective component for passive solar radiation use.
- Solar radiation is computed in relative terms, Figure 3 shows the solar irradiation chart of façades: solar radiation losses for different orientations are shown in colours, relative to the annual direct solar radiation incident on an “optimal façade”, defined as a south-oriented one free from shadows during 4 hours centered on solar noon.
- The limit for maximum acceptable losses has been considered to be 40%, similar to the one established for solar active use by the Spanish Technical Building Code [2]. This limits the acceptable façades orientation to the range 59º East – 60º West, which greatly increases the strictly south orientation typically considered in many passive solar studies.
- Losses due to shading effects during the 4 hours period are also computed, in order to identify the acceptable façades fraction.

[a] This tool is presented within POLIS Tool box compilation, see “Software tool for solar radiation and shading effects calculations”.



[Source: Software tool of the Solar Energy Institute (Instituto de Energía Solar) – Technical University Madrid]

Figure 3. Direct solar irradiation chart of façades in the "under-heated" period

Step 3. Solar potential categorization

Presentation of results in urban maps is done using a colour-based scale similar to the one used for Energy performance of buildings categorization [11]. In the following figure an example of a building passive solar potential assessment is shown. In this case, of the three building façades two have "C" solar potential (losses between 10-20% with respect to an optimal façade); the third façade has been divided in three sections due to shading self-inflicted by the building's left wing, with two parts having "C" and "F" potential and the remaining part having solar radiation losses over 50%. Would the building shape be a linear block with equal orientation (south-west), the solar potential would have shown just 10-20% losses compared to an optimal façade (code "C"). With this example it is clearly shown how the shape of the building determines its solar potential.

The associated data-base contains individual data of each façade, such as: associated building reference, orientation, solar radiation losses and solar potential code.

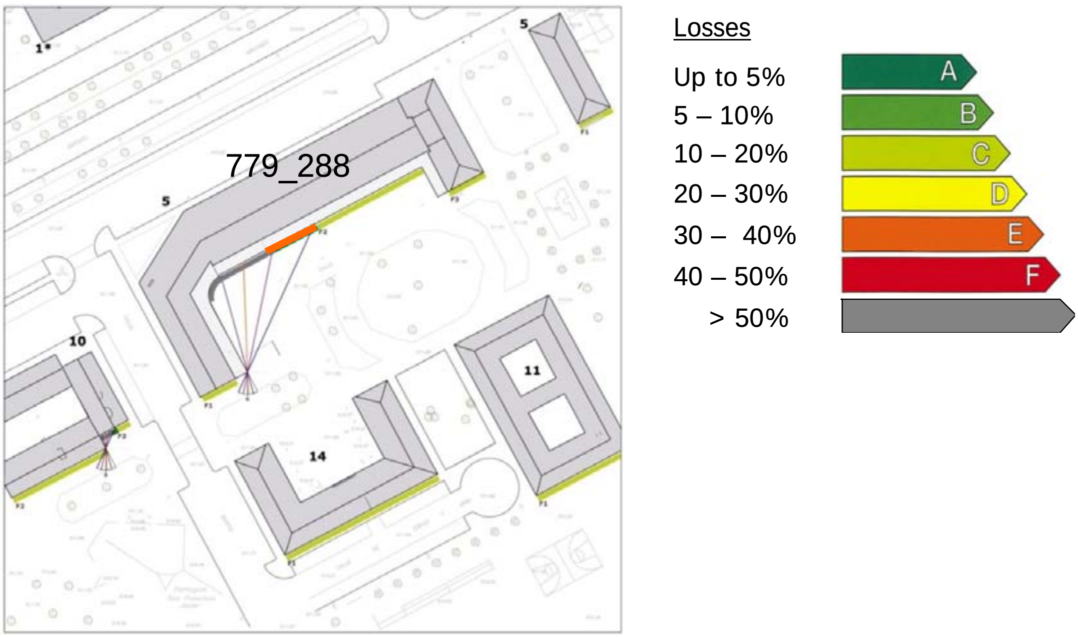


Figure 4. Passive Solar potential results: detail of an individual building assessment

1.1.3. Active solar potential assessment

As mentioned before, a combined assessment of solar thermal and solar photovoltaic potential is carried out, where the supply of domestic hot water and heating needs is considered the first priority.

Step 1. Identification of constructive elements and basic structural analysis

First of all, identification of the useful constructive elements is done, with the following criteria: only elements of common use with a surface bigger than 15 m^2 are analysed.

For the basic structural analysis 3 roof typologies (flat/tilted with concrete framework, light tilted and ventilated tilted) and 3 façade typologies (brick, light and prefabricated concrete) typical of the district buildings are defined. Structural loads (permanent & overloads) are computed in order to determine the constructive elements suitability for typical active solar components: solar thermal collectors and PV modules.

Step 2. Solar resource assessment

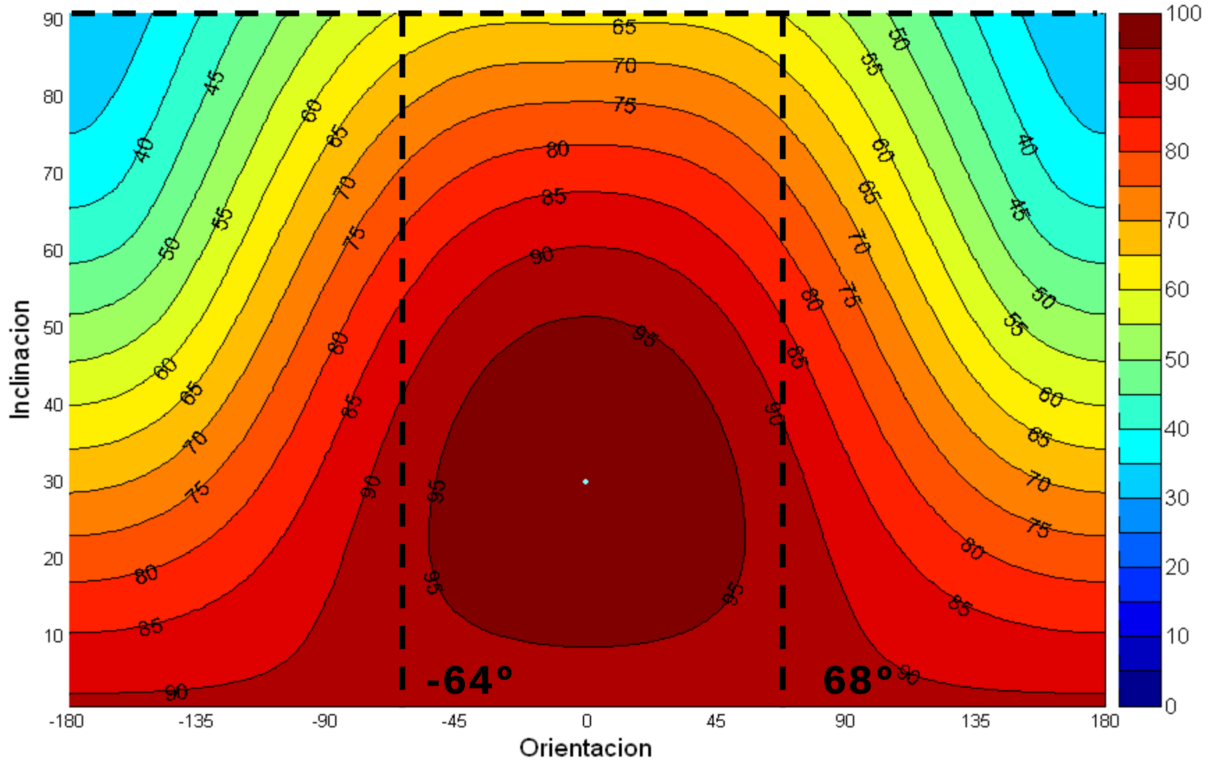
For active solar use, annual global solar radiation incident on the constructive elements is computed:

– Maximum acceptable losses are 40%, according to the limit established by the Technical Building Code [2] for building-integrated solar systems.
– Shadow losses are also computed in order to identify the acceptable constructive elements (maximum acceptable losses, 20%).

Figure 5 shows the global solar irradiation chart of Vitoria-Gasteiz, where for each orientation (*x* axis) and tilt angle (*y* axis) the solar resource available is shown in terms of losses relative to an optimal surface (south oriented and 32º tilted, with an incident solar irradiation of 1455 kWh/m^2). In the figure, the limiting acceptable orientations for façades are also shown with discontinuous lines: 64º East and 68º West.

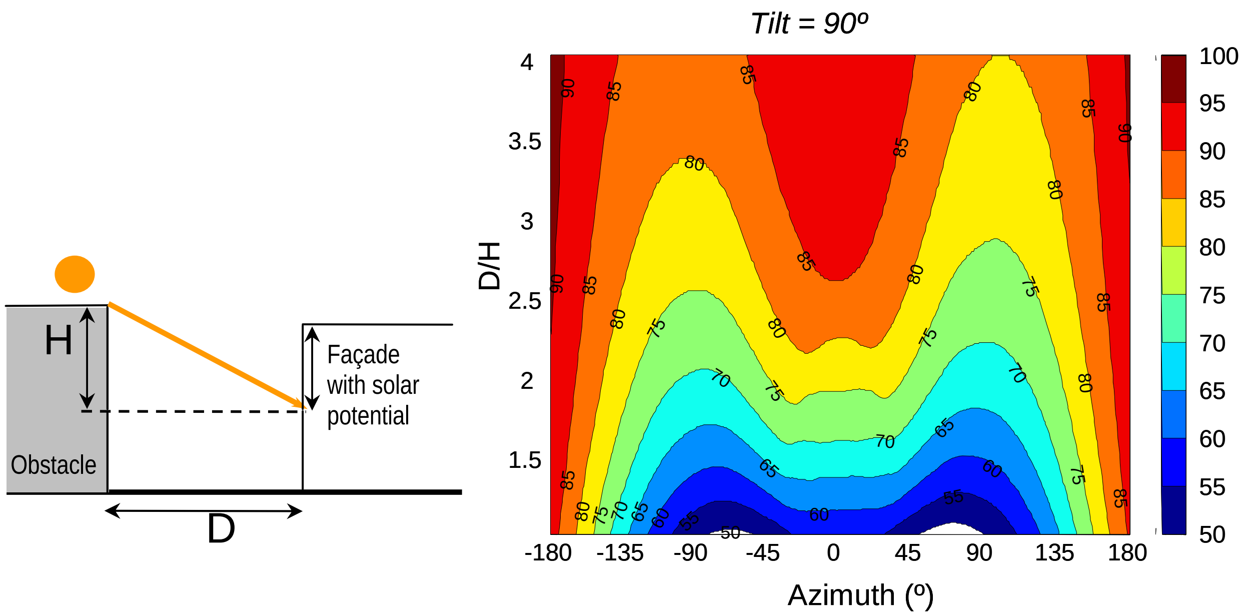
Figure 6 shows the approach used to analyse losses due to shadows incident on building façades coming from external obstacles, in terms of the ratio (see left part of the figure): H(obstacle height) / D(distance to obstacle); the chart on the right shows the solar radiation losses for different façades orientations and D/H ratio.

Figure 7 shows another example of shadow losses analysis using UPM-IES software tool that has been used when shadows are produced by external buildings and the own building's construction elements. In this case, after entering the coordinates of the obstacles, the tool constructs the building's obstacles profile and compares it with the annual sun trajectories in order to calculate the blocked components of global annual solar irradiation.



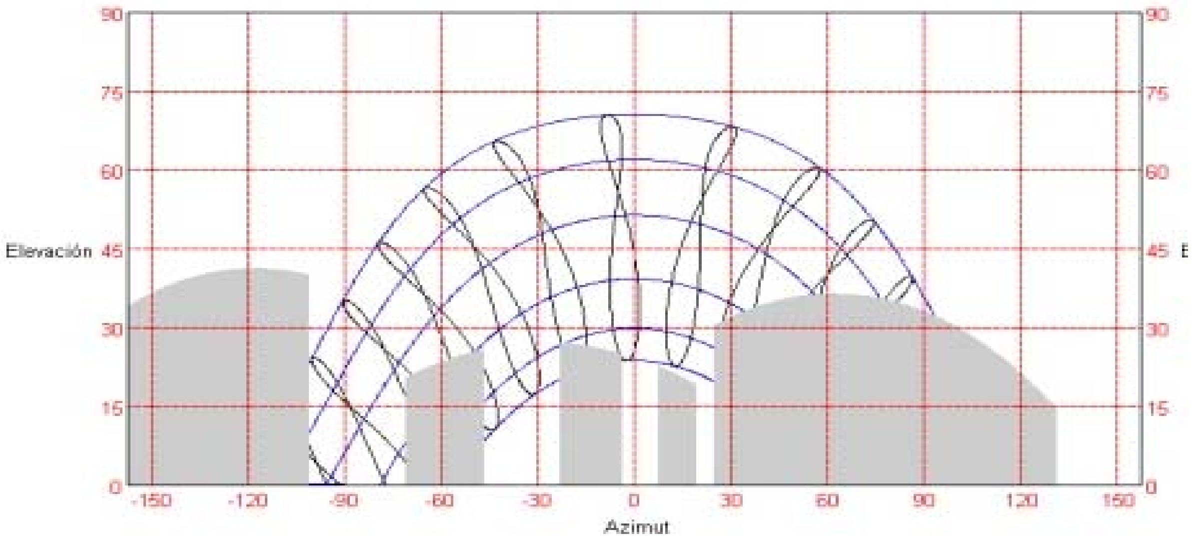
[Source: Software tool of the Solar Energy Institute (Instituto de Energía Solar) – Technical University Madrid]

Figure 5. Annual global solar irradiation chart of Vitoria-Gasteiz



[Source: Software tool of the Solar Energy Institute (Instituto de Energía Solar) – Technical University Madrid]

Figure 6. Shadow losses analysis of buildings façades (case I: external obstacle)



[Source: Software tool of the Solar Energy Institute (Instituto de Energía Solar) – Technical University Madrid]

Figure 7. Shadow losses analysis using UPM-IES software tool (case II: external + internal obstacles)

Step 3. Solar thermal potential: calculation of needs and nº of solar collectors

Assessment of the solar thermal potential starts with an estimation of the energy needed to supply Domestic hot water and Heating needs:

- Domestic hot water needs are estimated following the specifications of the Technical Building Code and Vitoria-Gasteiz Energy Ordinance draft [1,2].
- Heating needs through façades and roofs constructive elements are estimated using the Degrees-day method [12,13].

Then calculation of the number of solar collectors needed to supply a realistic percentage of the previous energy needs (see next step) is carried out using the f-chart method [14] and a high-efficient solar collector[b].

Step 4. Solar thermal potential: solar potential categorization

Solar thermal potential results are shown in the maps following a two colour code depending on the suitability of the construction element analysed:

- Green → suitable;
- Gray → not suitable.

Suitable construction elements also include two numbers:

- nº of collectors needed to cover 50% of Domestic hot water needs
- nº of collectors to cover 35% of Domestic Hot water + Heating needs

The associated data-base contains individual data of each building constructive element (roof & façade), such as: associated building reference, orientation, tilt, surface available, solar radiation (incident and losses), suitability for solar thermal installation and number of collectors to cover the building energy needs.

[b] Optical efficiency: 0,854; Linear losses coefficient: 3,37 W/m^{2}C.

The following figure shows an example of a building solar thermal potential assessment. Of all existing roof constructive elements, 8 are suitable for holding solar thermal collectors, the optimal one being the one for which the minimum nº of collectors would be required to provide the previously described solar fractions: 30 for supplying 50% of Domestic hot water needs and 65 for supplying 35% of combined Domestic hot water + Heating needs. The gray lines shown around the façades mean that these are not suitable for holding the numbers of solar collectors needed.

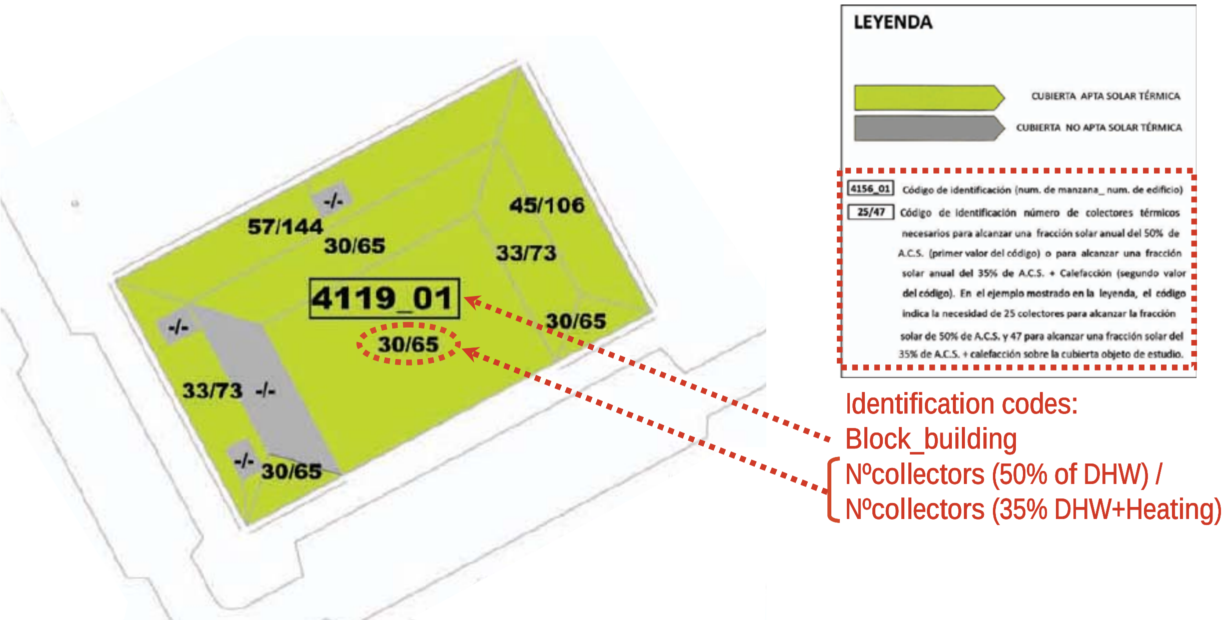


Figure 8. Solar thermal potential results: detail of an individual building assessment

Step 5. Solar photovoltaic potential: solar potential categorization

Six categories are used, which correspond to solar radiation losses ranges relative to an optimal surface (south oriented, 32º tilted) that are defined in the Technical Building Code for PV systems in buildings [2]. Each category is associated to a different colour, similar to the ones used in the passive solar potential analysis.

The following figure shows an example of a building solar photovoltaic potential. Of e 9 identified roof constructive elements, 3 of them (C3, C5, C7: dark green colour) have the best potential with losses below 5% with respect to an optimal surface); 2 (C4, C8: light green) have between 5 and 10% losses, 1 (C2: yellow) has losses between 20 and 30% and 1 (C1: orange) has losses between 30 and 40%. The remaining ones are not suitable due to losses over 50%. Of the façade constructive elements, 2 (F1 and F3: orange lines) have losses between 30 and 40%, 3 (F2, F4, F5: red lines) have losses between 40 and 50% and the remaining 2 ones are not suitable due to losses over 50%.

The associated data-base contains individual data of each building constructive element (roof & façade), such as: associated building reference, orientation, tilt, surface available, solar radiation (incident and losses), suitability for solar photovoltaic installation and solar potential colour code.

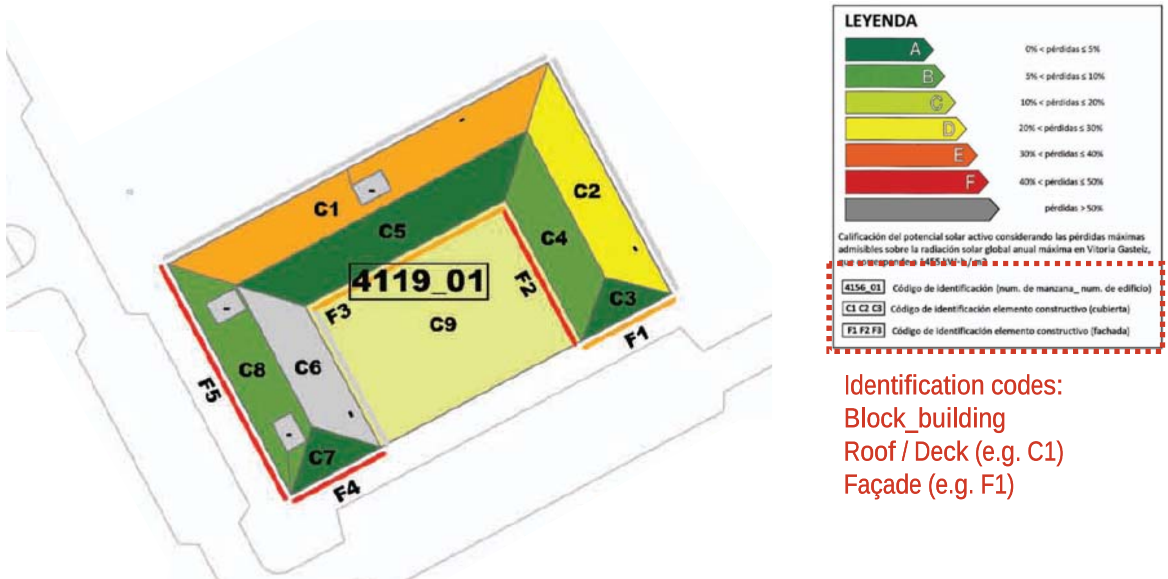


Figure 9. Solar photovoltaic potential results: detail of individual building assessment

1.2. Outcomes of the tool

The methodology developed allows a detailed and integrated identification of urban passive and active potential, where results are presented in a set of maps using a graphical way of straightforward interpretation:

- The solar passive potential is determined after detailed study of the climatic conditions, especially the solar resource, and the assessment of buildings façades orientations.
- The solar active potential is determined after assessment of buildings constructive elements of roofs and façades orientation, tilt (roofs' case), shape, constructive and structural characteristics.
- Advantages and oportunities of each building typology are identified by looking at buildings typology, shape, constructive and structural characteristics, and micro-climatic environment.

The previous results suggest developing complementary instruments, such as:

- A Bioclimatic ordinance if the methodology is applied to an urban residential area, with basic recommendations for a more efficient design of residential buildings using low-cost measures. Some of these recommendations have been included in the application of the methodology to Vitoria-Gasteiz residential district of Lakua.
- Proposals for improving the passive thermal conditioning of buildings envelope, with the aim of increasing their thermal inertia, an essential aspect for the most under-heated months. This could be of direct application for the buildings retrofitting sector.
- Recommendations for the design of new buildings, with the aim of optimising their energy production possibilities using solar passive technologies. These have been included in the application of the methodology to Vitoria-Gasteiz industrial area of Jundiz.

- Assessment of the potential energy balance of the urban area under study by comparing the solar potential identified with real (or estimated) consumption data of buildings.
- Dissemination campaign to raise awareness of the existing solar potential between relevant stakeholders: citizens, municipality, professionals and industry associated to solar energy and construction sector.

1.3. Assessment of the tool

1.3.1. Advantages / Disadvantages

Advantages of the methodology are the following:

- Integrated assessment of solar active and passive potential, combining national & local technical requirements for solar energy use. Usefulness of integrated approach:
  - Highlights differences between buildings typologies → Priorities can be established at urban planning and/or urban renovation levels.
  - Illustrates the wide solar potential available at urban scale, useful to promote adequate constructive elements for solar energy potential mobilization (e.g. solar passive elements, structural elements for solar active systems).
  - Optimal location for solar active installations can be easily identified from the colour-based categorization system used.
  - Powerful tool to raise political and public awareness of the energy and economical benefits of using solar energy at urban scale.
  - Provides new perspectives for the Construction sector in the field of urban retrofitting.
- Detailed identification of the solar potential available in buildings:
  - Application of urban filters (e.g. year of construction, patrimonial protection, minimum available surfaces) allows assessing the solar urban potential in realistic terms.
  - Solar radiation incident is translated into potential useful energy (solar passive use) and potential energy generated (solar active use: solar thermal and photovoltaic).
  - Provides individual solar potential at building scale → Exploitation can be directly promoted by the building owners (e.g. Homeowners Associations)
  - Simplified structural analysis allows evaluating the suitability of existing buildings. (Note: it does not substitute the analysis that would be required to mobilize the solar potential identified).
  - Results are shown in digital maps, creating useful information for urban planners
- Compatibility with GIS allows establishing relationships between energy and socio-economical factors → Powerful tool for decision making in urban design and retrofitting.

As disadvantages, the main aspect identified is the necessity of workflow automation, especially for the solar thermal potential assessment and for shadows cast evaluation. The methodology developed is extremely time-consuming.

1.3.2. Improvements

- Categorization of buildings in terms of orientation, shape, age, height-to-street-width, structural characteristics, etc., to avoid analysis at individual buildings scale.
- Automatization of solar radiation assessment, including shadows, using GIS calculation tools
- Identification of public spaces' solar potential.
- Analysis of urban areas energy consumption related to potential energy generated through solar energy systems.

1.4. Examples

The methodology has been applied to two large urban areas of the city of Vitoria-Gateiz:

- Lakua, a residential district located in the northern part of the city (376 Hectares): 126 maps have been produced, 42 for solar passive and 84 for solar active potential.
- Jundiz, an industrial area located in the west part (710 Has.): in this case only the solar photovoltaic potential has been assessed due to the interest of the municipality in this technology for the area under study. 56 Maps have been produced.

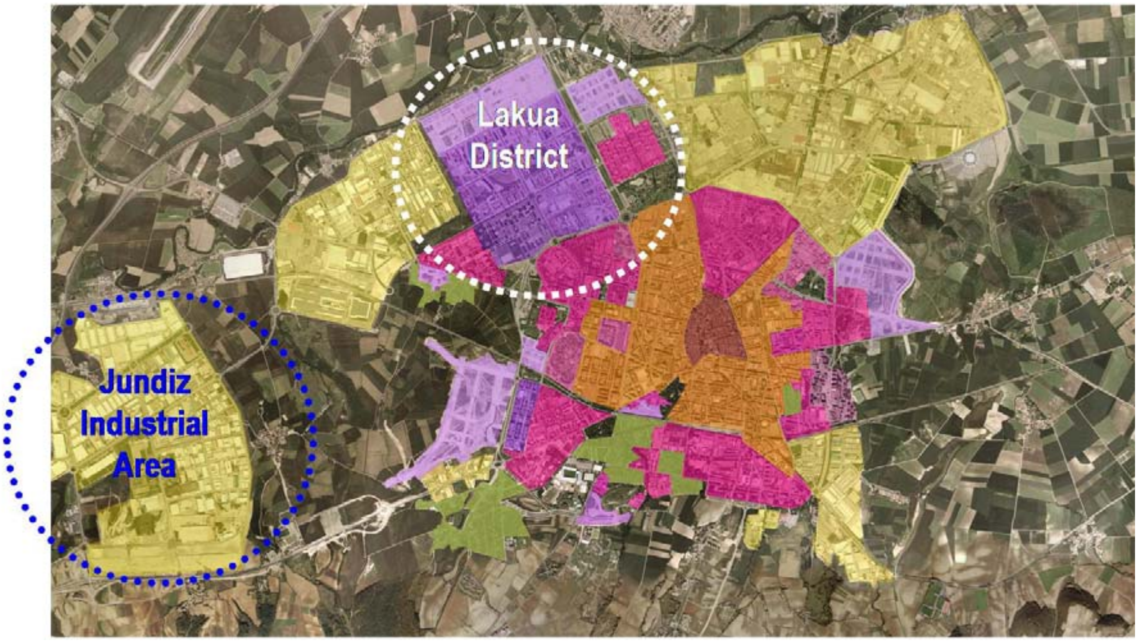


Figure 10. City of Vitoria-Gasteiz and areas under study

An example of passive solar potential map is shown in Figure 11, particularly map nº12 of the 42 covering the residential area of Lakua. In this case, due to the south-east orientation of the buildings all façades have "C" potential; shading affects some buildings with "U" shape, but no shading occurs between buildings due to the distances between them (low urban density). Figure 12 and Figure 13 show respectively examples of active solar thermal and photovoltaic potential maps (maps nº 16).
Figure 14 shows an example of active solar photovoltaic potential map of Jundiz industrial area.

Figure 11. Passive Solar potential map: example of Lakua residential district

Figure 12. Active Solar thermal potential map: example of Lakua residential district

Figure 13. Active Solar photovoltaic potential map: example of Lakua residential district

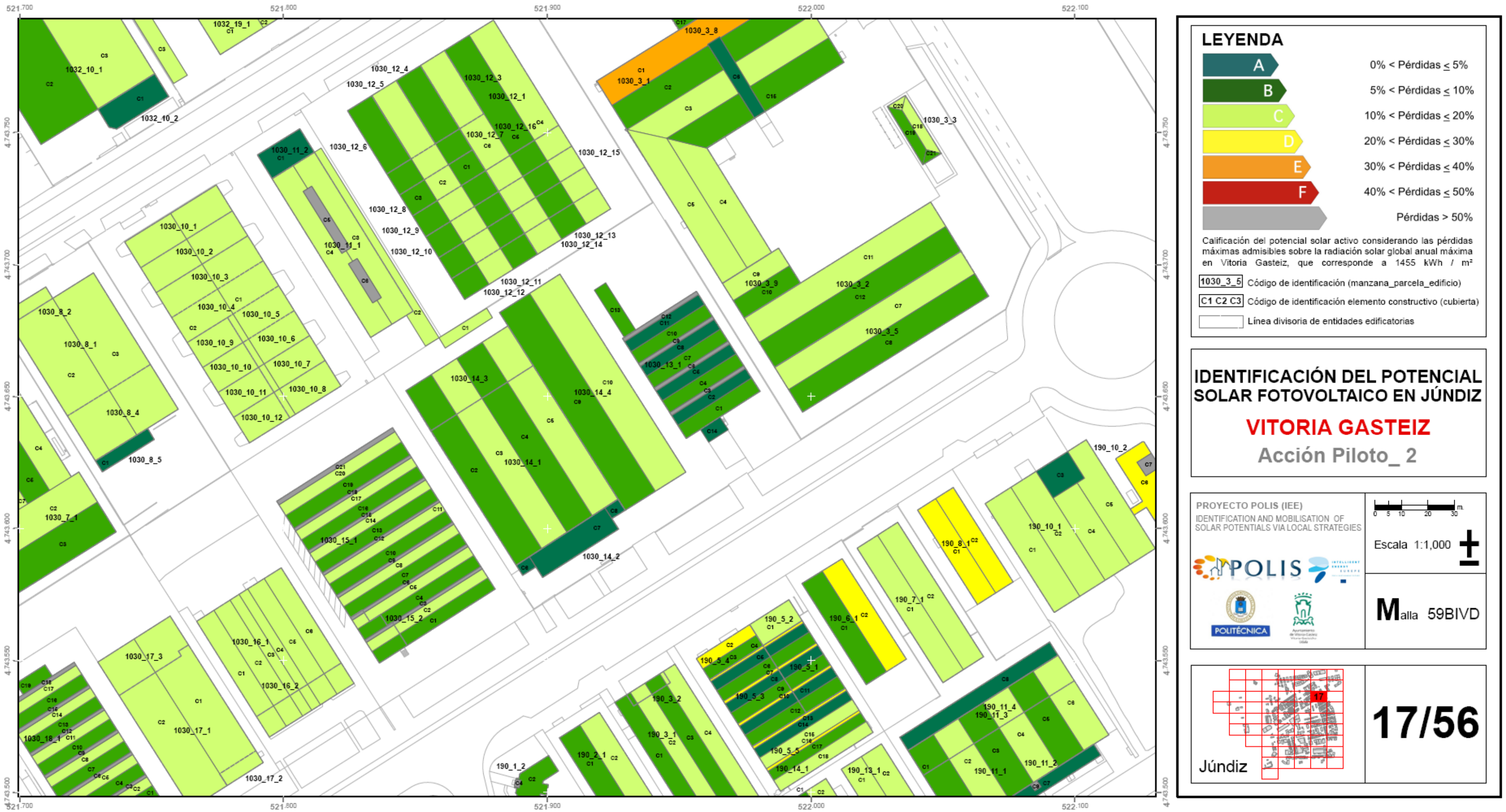


Figure 14. Active Solar photovoltaic potential map: example of Jundiz industrial area

1.5. Literature

[1] Vitoria-Gasteiz city Council, “Energy Ordinance of Vitoria-Gasteiz” draft, 2008.

[2] Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación. See also: Orden VIV/984/2009, de 15 de abril, por la que se modifican determinados documentos básicos del Código Técnico de la Edificación aprobados por el Real Decreto 314/2006, de 17 de marzo, y el Real Decreto 1371/2007, de 19 de octubre. <http://www.boe.es>

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