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The influence of Daylight in the Housing Market

A case study in Turin

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Abstract

Daylight is essential in the architectural field, since the preliminary design stages onwards, and along all the life cycle of a building. It influences the psychological and physiological aspects in human beings, as well as the energy efficiency of a building, as it can contribute to decreasing the energy demand for electric lighting and cooling. As a consequence, daylight is often mentioned above the most important factors by people when it comes to buying or leasing an apartment, which means that daylight can play a role in the determination of prices in the real estate market.

Within this frame, the aim of this thesis is to investigate and to try to quantify the impact of daylight in the real estate. A data sample of 100 housing units was built, selecting units in the district called *Pozzo Strada*, in Turin. The sample includes both *classic variables* as taken from the market advertisements, such as the surface of the unit, the construction year of the building, the location, and the view, as well as some *green variables* related to daylight, such as the type of glazing (single or double) and frame (wood, PVC, or aluminium) used in the window. Particular attention was paid to the daylighting amount inside the units, calculated through simulations in terms of average Daylight Factor, or through other climate-based daylight metrics (spatial Daylight Autonomy, Useful Daylight Illuminance, and Annual Sunlight Exposure). These climate-based daylight metrics have been found through simulations using the validated software ClimateStudio and inserted in the database. Once complete, a Multiple Regression Analysis is carried out, starting from the Spearman Correlation Analysis and followed by the removal of the outliers, if present. After multiple models with the listing price per square meter as dependent variable, a final Multiple Regression Model to explain the significant factors on the final price of an apartment was defined.

The final results demonstrated the relevance of daylight in the real estate, and at the same time identified which of the new *green variables* included are actually significant. Among them, the Annual Sunlight Exposure resulted significant and with a positive marginal price, together with the façade typology. Although significant, the frame typology resulted in a negative marginal price. To a minor extent, the Useful Daylight Illuminance was also found to be significant, while the average Daylight Factor didn't.

Keywords: climate-based daylight metrics, daylight, Daylight Factor, implicit marginal price, listing price, Multiple Regression analysis, real estate market, view out.

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Introduction

In this study it has been investigated the role daylight has in the real estate, its quantification, and the possibility of it as a monetary value. Daylight is essential for the well-being of humans, and it influences the energy efficiency of a building. When a unit has ‘good’ daylighting, the energy demands due to artificial lighting and cooling tends to decrease. The element daylight is included in most of the norms and regulations such as *ITACA Protocol*, *LEED Protocol*, and *WELL Protocol*, which provide indications for its calculation, the performance scale benchmarks, and the relative score according to the results achieved. The metrics used for defining daylight are multiple: from the rule of thumbs based mainly on proportions, to the static average Daylight Factor (DF_m), to climate-based metrics found through simulations such as the spatial Daylight Autonomy (sDA), the Annual Sunlight Exposure (ASE) and the Useful Daylight Illuminance (UDI). In the Italian Building Regulations, the average Daylight Factor is always accompanied by RAI, the first including obstructions and window geometry and features, the second determined by the ratio between window and floor surface. Together with daylight metrics, many other variables that have been introduced in the study

are strictly correlated to each other and linked directly to daylighting, such as the façade and building geometry, the type of window (frame and glazing typologies), the quality of the views, the avoidance of glare, and the shading devices.
In the past, many studies have already taken daylight as a variable in hedonic pricing modeling, but this has been made mainly in working environments (offices), where daylight is used for increasing productivity, visual comfort, and general well-being. The same has not been done on residential units, and for this reason, this study wants to investigate the possible value daylight has in monetary terms, through the use of Multiple Regression analysis, taking as setting the city of Turin and the area called *Pozzo Strada*. It also aims at understanding which of the metrics used for quantifying daylight is the most indicative in this context, found through the significance in Multiple Regression Models.

The study is divided into two parts: the theoretical background of the research (1), including indications about norms and regulations for Daylight and the approach of Multiple Regression Analysis, and the Case-Study (2), including simulations and Multiple Regression Models. In Chapter 1 the fundamentals of daylight have been reported, with all its advantages, and also the main study from which this research took inspiration has been cited. Chapter 2 focuses on the norms and regulations about daylight, such as the *LEED Protocol* and *ITACA Protocol*, distinguishing Daylight Factor-based and climate-based metrics. In Chapter 3 the concept of Multiple Regression has been introduced, which is the approach used for determining the predictive and explicative model. The second part starts with Chapter 4 including the methodology and the workflow of the study, while Chapter 5 provides all the data sampling information and results. Chapter 6 contains information about the software and the daylight simulations that has been carried out, as well as the Multiple Regression Models, followed by Chapter 7 where the Multiple Regression model obtained as the final result is discussed and conclusions are drawn.

<u>PART I</u> - Theoretical Background of the Research

Chapter 1
Fundamentals of Daylight

1.1 Introduction

Although sunlight, natural light, daylight, and daylighting are related to the same concept, they all differ from each other. Sunlight is the direct light from the Sun, natural light is any light provided by a natural source in both direct (Sun) and diffuse (sky) form, and finally, daylight and daylighting are related because daylighting is the successful design in including a *proper* quantity of daylight and a consequent improvement in energy efficiency. A good daylighting design, in fact, decreases the use of artificial light, resulting in fewer energy demands.
Literature expands on the effects of daylight in a working environment, but the influence in residential units are not as widely considered. Daylight guarantees the well-being of humans, increasing productivity, concentration, creativity, and mood, while decreasing stress[1].

1.2 What is Daylight?

Good lighting, natural and artificial, is the combination of **efficiency** and **comfort**, in relation to the building typology and the function[2]. Light is distinguished into four different levels: *functional*, *aesthetic*, *emotional*, and *somatic level*[3], and the aim of designers is to manipulate it in order to obtain the desired objectives. The *functional* layer is the "*easiest*" to assess because many norms and regulations provide designers with threshold values to be reached and guidelines for a proper daylight design through different metrics. The *aesthetics* layer is given by the shadows' dynamicity and by the luminance and brightness contrasts, with a combination of materials

[1] I. Turan *et al.*, (2021), *Development of View Analysis Metrics and their financial Impacts on Office Rents*, MIT Center for Real Estate Research Paper No. 21/03, MIT - Center for Real Estate, p. 1.

[2] M. Bonomo, (2008), *Illuminazione d'interni - Teoria, Tecniche, Apparecchi, Progettazione di impianti, Applicazioni*, Maggioli Editore, p. 1.

[3] M. Corrodi, K. Spechtenhauser, (2004), *Illuminating*, ETH Swiss Federal institute of Technology Zurich, Birkhauser, p.21.

and colors, mostly reached by interior designers with artificial light[4]. The *emotional* layer is subjective and identified by *atmospheric* or *mood lighting*[5], while the *somatic* layer regulates our *hormone balance and our vegetative and chronobiological circulation*[6]. Light is the essential energy for the Planet, including the human species, and it is the result of radiations on our eye, directly in the case of the Sun or other light sources, diffuse or reflected in other cases[7].

Light is measured with (*Figure 1*):

- luminous flux Φ_l (lm, lumen), defined as the quantity of energy emitted over time by a source;
- luminous intensity I_l (cd, candela), defined as the light concentration in one direction[8];
- luminance L (cd/m²), defined as the ratio between luminous intensity in one direction and the area of the surface;
- illuminance E (lx, lux), defined as the luminous flux received by a surface uniformly, which depends on the type of area and activity. For example, it goes between 300 and 500 lx in the case of schools, with 750 lx in the case of drawing classrooms. A lux meter is one of the portable instruments used to determine it manually[9];
- luminous emittance M (lm/m²), referred to a surface;
- correlated color temperature CCT (K, Kelvin), defined as the totality of the color emitted by a light source, where 2000 K is the light from a candle, up to 8000 K in the case of sky white, almost blue. The higher the value, the colder the light would appear. A cold light is more suitable for working spaces where it enhances concentration. During the day the correlated color temperature varies from 2000K at sunrise, to up to 6500K at noon, and again to 2000K at sunset (*Figure 2*). The color is based on the CIE[10] X, Y, Z where any color is the result of the combination of the three colors: red in X, green in Y, and blue in Z (*Figure 3*)[11].

[4] M. Corrodi, K. Spechtenhauser, (2004), *Illuminating*, ETH Swiss Federal institute of Technology Zurich, Birkhauser, pp.22-23.
[5] *ibidem*, p. 24.
[6] *ibidem*, p. 25.
[7] *ibidem*, pp. 130-133.

[8] M. Bonomo, (2008), *Illuminazione d'interni - Teoria, Tecniche, Apparecchi, Progettazione di impianti, Applicazioni*, Maggioli Editore, pp. 10-13.
[9] *ibidem*, p. 36.

[10] CIE: International Commission on Illumination, 1931.

[11] M. Bonomo, (2008), *Illuminazione d'interni - Teoria, Tecniche, Apparecchi, Progettazione di impianti, Applicazioni*, Maggioli Editore, p. 52.

Symbol		**Measure Unit**
Φ_l	**Luminous Flux**	Lumen (lm)
I_l	**Luminous Intensity**	Candela (cd)
L	**Luminance**	(cd/m²)
E	**Illuminance**	Lux (lx)
M	**Luminous Emittance**	(lm/m²)
CCT	**Correlated Color Temperature**	Kelvin (K)

Figure 1 Light unit measures. (Source: Re-elaborated by the author from Torricelli Maria Chiara, Marco Sala, Secchi Simone, (1995), *Daylight: La Luce del Giorno*, Alinea editrice p. 19).

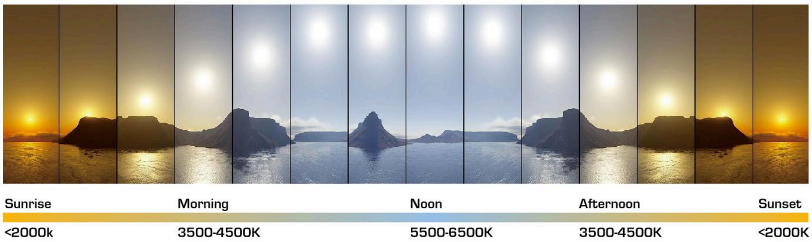

Figure 2 Correlated Color Temperature (CCT) during the day. (Source: https://www.it.lumistrips.com/lumistrips-blog/color-temperature-explained-it/).

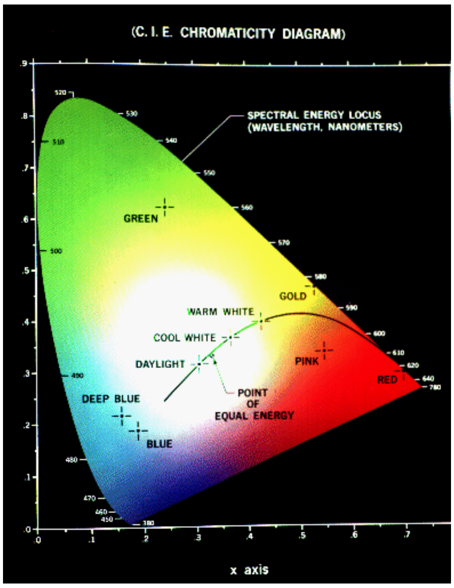

Figure 3 C.I.E. Chromaticity Diagram with all visible colors. (Source: https://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/OWENS/LECT14/lecture12.html).

For the light to be visible to the human eye, the wavelengths need to be in the frame between 380 and 780 nm, with a higher response at 555 nm[12] (**human spectral sensitivity**[13]).

The variation in wavelengths and radiances differs the visual sensations in color and brightness, and the eye has the capability to adapt to these phenomena[14]. The **Photopic vision** is the vision referred to the day, where there is plenty of light and where the maximum visibility factor is at 555 nm (yellow-green light), while the **Scotopic vision** is the one referred to the night with a maximum visibility factor of 510 nm. The shift from 555 to 510 nm is known as the Purkinje effect (*Figure 4*).

[12] M. Bonomo, (2008), *Illuminazione d'interni - Teoria, Tecniche, Apparecchi, Progettazione di impianti, Applicazioni*, Maggioli Editore, p. 52.

[13] *sensibilità spettrale*

[14] M.C. Torricelli *et al.*, (1995), *Daylight: La Luce del Giorno*, Alinea editrice, pp. 95, 124-125.

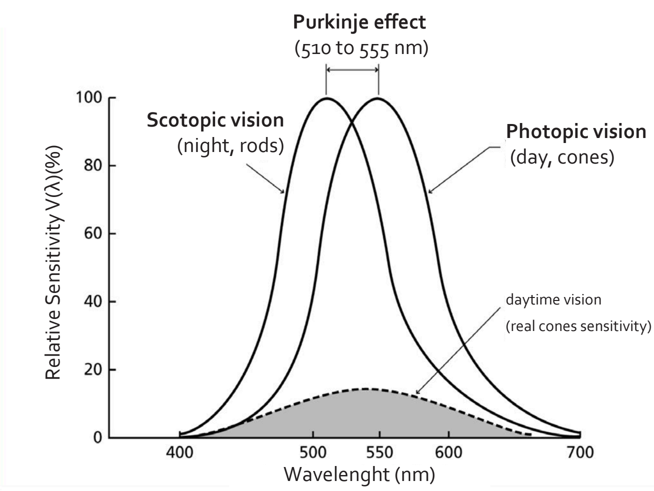

Figure 4 Scotopic and Photopic visions.
(Source: https://www.unirc.it/documentazione/materiale_didattico/597_2009_223_4910.pdf).

When below 500 nm the colors blue and purple are seen, when above 500 nm green, yellow, orange, and red are seen consequently. Outside of those limits, the ultraviolet (<380 nm) and the infrared rays (>780 nm) are reached (*Figure 5*).

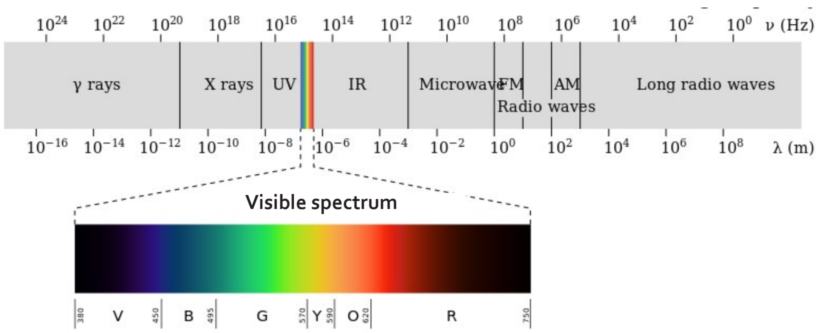

Figure 5 Visible Light Wavelengths representation.
(Source: https://www.lumitex.com/blog/visible-light-spectrum).

Natural light is the combination of the direct sunlight components, which is the Sun, the diffuse skylight component by the atmosphere, the sky dome, and the reflected light due to the ground. The solar diagram changes according to the setting and *Figure 6* reports Turin's case.

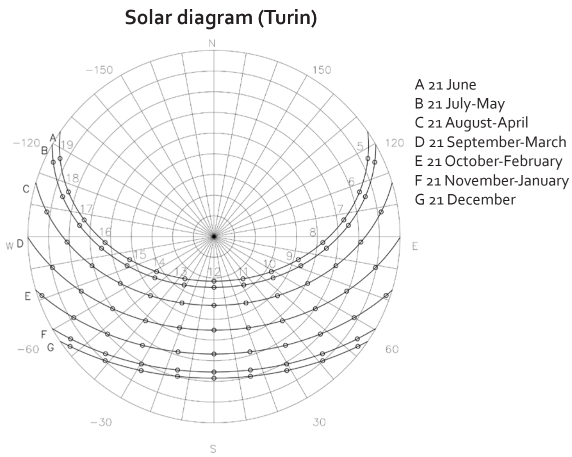

Figure 6 Turin's Solar Diagram.
(Source: http://www.comune.torino.it/ediliziaprivata/moduli/pdf/ae_dia_sp2000%20Model.pdf).

The diffuse skylight component (sky dome) depends on the sky models. The sky models are multiple; the "All-sky weather" of Perez has, for example, all 8 sky conditions, from the clear sky to the overcast sky (from best to worst possible scenario). The Weather Data are provided now worldwide for any location and the information provided contains all the weather data over one full year. The sky can also be determined graphically with the **Waldram diagram**, where the window and the external obstructions are reported and the percentage of the sky component is defined[15].

[15] M.C. Torricelli *et al.*, (1995), *Daylight: La Luce del Giorno,* Alinea editrice, pp. 169-170.

Daylighting Design provides both **visual** and **thermal comfort** while reducing the energy demand. Visual and thermal comfort are reached through the parameters: visible transmittance, visible reflectance, the direction of incidence/emission, the chromatic control (*color rendering index CRI*), the correlated color temperature (*CCT*), as well as the solar control (*solar heat gain coefficient*), and the thermal control (*thermal transmittance U-value*).

Daylight is dynamic, it creates a stimulating and productive environment providing overall psychological and physiological benefits to humans. It is a free and sustainable resource that, if carefully designed, decreases the energy demand for both electric lighting and summer cooling demands.

Daylight is a dynamic phenomenon, which depends on many factors such as:

- the building's surroundings (obstructions by buildings and vegetation);
- the climatic zone;
- the building volumes and façades;
- the building's orientation;
- the dominant sky conditions depending on the climatic zone (diffuse, clear, or overcast) and the atmosphere turbidity;
- the geometry and characteristics of the windows (glazing area and transmission properties; tinted, mirror, or low-emission glazing);
- the shading systems (such as horizontal and vertical shades as overhangs or blinds);
- the season;
- the time of the day[16] [17].

Together with all the above-mentioned aspects, daylight needs to be designed according to the building function and typology, including the occupancy hours. The consideration of all these aspects leads to the evolution of the approach from the average Daylight Factor to climate-based metrics (CBDM).

1.2.1 Pros of a better daylighting design

The natural light indoors is much more complex to study compared to outdoors, which could enter laterally (*side lighting*), or from above through skylights (*top lighting*), or with alternative systems (*core lighting*)[18]. 83% of human perceptions are reached with eyesight, becoming the most significant sense for human beings. The indoor environmental quality needs to be assured during the occupancy of the space and it is essential in the working environment, and more in general for human health[19].

The pros of a good daylighting design are multiple and can be summed up as:

[16] I. Turan *et al.*, (2021), *Development of View Analysis Metrics and their financial Impacts on Office Rents*, MIT Center for Real Estate Research Paper No. 21/03, MIT - Center for Real Estate, p. 7.

[17] M. Bonomo, (2008), *Illuminazione d'interni - Teoria, Tecniche, Apparecchi, Progettazione di impianti, Applicazioni*, Maggioli Editore, p. 5.

[18] E. Bonicelli, (1934), *La Luce Naturale in Architettura - Considerazioni generali ed applicazione*, Tipografia Edit. Umberto Franchini E C., Torino, p. 21.

- better visual comfort (appropriate illuminance level (lx) for the activity, adequate temperature color);
- well-being and comfort;
- higher productivity in working environments;
- energy savings due to the lower impact of artificial lighting and cooling demands, as well as decrease of peak electrical loads.

Daylighting has to be taken into consideration from the early stages of design onwards, spacing from the building's geometry and orientation, to the construction and finishing materials, to the solar shading devices and other external obstructions over the life of the building and the maintenance of all the systems. A good daylighting design does not reach the total substitution of artificial lighting with daylight, but aims towards finding the correct balance considering all the premises.

1.2.2 Circadian rhythm and visual comfort indoor

Natural light plays a big role in the well-being of humans, due to the circadian rhythm.

In 2001 for the first time *light poisoning* was introduced as harmful for humans, after *cryptochrome* was discovered as an addition to the receptors (rods for brightness and cones for color), and considered a functional hormone regulator and moderator of the body's daily and annual rhythms[20] and guaranteeing the well-being of humans, helping them to follow circadian rhythms, synchronizing to the phases of brightness during the day (light) and the sleep phase of the night (darkness).

The **circadian rhythm** is defined as the 24-hour cycle of day and night influencing the human sleep-wake cycle, due to the melatonin secretion released overnight. The luminous stimulus is needed for awakening in the morning, being attentive over the day when brightness is high, and favoring sleep in the evening for a better sleep quality overnight (*Figure 7*).

[19] M.C. Torricelli *et al.*, (1995), *Daylight: La Luce del Giorno*, Alinea editrice, p. 95.

[20] M.Corrodi *et al.*, (2004), *Illuminating*, ETH Swiss Federal institute of Technology Zurich, Birkhauser, p. 27.

Figure 7 Circadian Rhythm. (Source: https://www.infijoy.com/blog/rest-and-recovery/understanding-the-circadian-rhythm-for-better-sleep).

The visual or luminous environment is given, among the daylight characteristics entering through the openings (building geometry, external obstructions, and window geometry and characteristics), by the color and by the internal surfaces' reflection, by the view out as the contact with the outdoors, by the privacy, by the availability of direct sunlight, and by the variability of daylight during the day[21].

Very often the result in dealing with daylight is focused on the quantity instead of the quality, designing more and more frequently buildings made of glass. Daylight provision needs to aim for both quantity and quality, since an excess in daylight directly implies the presence of glare. The quality is linked to glare, direction, and color, which are directly connected to the luminous intensity[22]. Glare can be defined as **disabling glare**, when the direct or reflecting vision reduces the object's detail perception, or as **discomfort glare**, when there is a disturbing feeling which does not alter the objects, due to bad positioning of artificial lighting[23].

The color is not only to be considered from an aesthetic point of view, but can be used as an advantage in diminishing quantity and thermal energy transmission in the case of tinted glazing, reducing in this way the presence of glare and overheating[24].

1.2.3 The view out

Daylight is highly influenced by the context, as well as the views, which are of relevant importance both socially and economically in indoor quality environments[25], with a great impact on listing prices of residential units[26]. The views are highly influenced by the view angle and the depth-of-field, and a total of three layers can be seen, from the ground layer to

[21] M.C. Torricelli *et al.*, (1995), *Daylight: La Luce del Giorno*, Alinea editrice, pp. 127-128.
[22] *ibidem*, p. 98.
[23] *ibidem*, pp. 107-108.
[24] *ibidem*, pp. 122-123.

[25] I. Turan *et al.*, (2021), *Development of View Analysis Metrics and their financial Impacts on Office Rents*, MIT Center for Real Estate Research Paper No. 21/03, MIT - Center for Real Estate, p. 2.
[26] *ibidem*, p. 6.

the natural or urban landscape and the sky layer, and they are defined by the European Norm *EN17037:2018 Daylight in Buildings*[27], as well as in *LEED*[28] where quality views must include nature, sky, or movement at 7.5 meters from the façade.

1.3 Advantages of Daylight - Case studies

In literature there are many studies including the quantification and the valuation of daylight, in order to demonstrate the importance it has in human productivity, satisfaction, and a stress-free environment, especially in workplaces. Many are the standards and regulations including daylight widely reported in *Chapter 2*. Among other characteristics, a 'good' daylighting can guarantee scores for obtaining Building Certifications. Since daylight demonstrates having a positive impact both on human well-being and on energy savings, it can be defined as a sustainable variable. In this study, it is researched the value of daylight in economic terms in the case of residential units, following previously done studies in workplaces.

1.3.1 Case Study 1

In *The value of daylight in office spaces*[29] a study has been carried out, demonstrating the link between the social benefits of daylight, as well as the well-being and productivity, and its economic value. 5154 office spaces with their rental price in Manhattan, NY, is the sample used for this study, and both daylight simulation and the hedonic valuation model are used to determine the marginal value of daylight in **office rental spaces**. The value for defining daylight used in the hedonic model is the **spatial Daylight Autonomy (sDA)**, with 'low' results when sDA is between 0% and 55%, 'high' when it is above 55% and below 75%, and finally, 'very high' sDA is when over 75%, as reported in *LEED*. Spatial Daylight Autonomy measures in percentage the area of the floor surface receiving *enough* daylight (300 lux). The 3D models have been all assumed with a window-to-wall ratio of 30% and with a floor-to-ceiling height of 3.5 meters, disregarding any internal partition, blind, core spaces, or

[27] CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels.

[28] US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction.*

[29] I. Turan *et al.*, (2019), *The value of daylight in office spaces*, Building and Environment 168 (2020) 106503, pp. 1-13.

furniture. For the simulations, these reflectance values have been used:

- wall 50%;
- floor 20%;
- ceiling 70%;
- exterior façade 30%;
- ground 20%;
- window 96% reflectance with 88% transmittance.

The first stages of the workflow consisted in these three phases:

1. The collection of data from 5154 offices, in a total of 905 buildings spread all over Manhattan (New York City);
2. The 3D Modeling of each building with its surroundings representing the external obstructions influencing the daylight results;
3. The calculation through simulations of $sDA_{300/50\%}$ based on the hourly illuminance value for both direct and diffuse light, found floor by floor, defining the total potential daylight over the year.

Once all the data has been found, the study follows with the hedonic model, using as a dependent variable the **net effective rent**, which explains 60% of the rental price market. Some of the variables included with the sDA data and the rental price are the building's age, whether it is *LEED* certified, the lease term duration, the free rent period, the floor number, and the landlord concession. As a result, the average sDA found is only 43% and 74% of the units have sDA below the *LEED* benchmark (sDA<55%). The daylight result demonstrates individuality and independence over building characteristics, location, and type of contract. A link is instead found between sDA and the floor allocation of the units, where the higher the floor, the higher is also the total potential daylight. When sDA results are higher than 55%, a 5-6% value is added when compared to spaces with sDA below 55%. This study demonstrated the economic value of daylight in the real estate market, in order to share the fact that more importance should be given in every design phase to guarantee better daylight conditions.

1.3.2 Case Study 2

In the study *Development of View Analysis Metrics and their financial Impacts on Office Rents*[30], the previous study has been integrated with aspects related to the views, combining **spatial View Access** (sVA_3) and **spatial Daylight Autonomy** (sDA) as a representation of daylight. The spatial view access is determined by the number of rays reaching elements such as neighboring buildings, ground, iconic landmarks, green spaces, water, and sky, and the higher the floor of the unit considered, the higher is both the view quality and the daylight expected. The

[30] I. Turan *et al.*, (2021), *Development of View Analysis Metrics and their financial Impacts on Office Rents*, MIT Center for Real Estate Research Paper No. 21/03, MIT - Center for Real Estate, pp. 1-42.

potential view quality and daylight can be found in the preliminary stages of design. A high view access is found when at least 10% sVA_3 is found. As a result, 64% have neither 'high' daylight nor views, 19% have 'high' daylight only (over 55% sDA), 8% have 'high' views only, and 8% have both 'high' daylight and views. The dependent variable used in the hedonic pricing model is the **logarithm of the net effective rent** in U.S. Dollars[31]. In the 8% cases of both 'high' daylight and views, the result is an addition of 5.3% of net effective rent for 'high' daylight and 6.3% for 'high' views. When combined, the value increases by only 6.5%, basically reaching the value obtained by their own, demonstrating their link and at the same time their independence from one another. The result of this study proves that daylight and quality views have a positive value (5-6% financial premium), and this is an important result for providing adequate pricing in the real estate market for both tenants and landlords[32].

[31] I. Turan *et al.,* (2021), *Development of View Analysis Metrics and their financial Impacts on Office Rents*, MIT Center for Real Estate Research Paper No. 21/03, MIT - Center for Real Estate, pp. 13-14.
[32] *ibidem,p. 10.*

1.4 Summary

Daylight is one of the cores of architectural design, capable of assuring energy efficiency and visual and thermal comfort. It is dynamic and complex, and has a big influence on the well-being, mood, and productivity of the occupants due to the circadian rhythm. Due to its importance and complexity, daylight design needs to be carried out from the early stages of design and accompany the life of the building until its end. The two studies cited have carried out analysis with hedonic pricing models, researching the role of daylight and view access on the rental market in office spaces in Manhattan, New York. Daylight has been quantified with the metric spatial Daylight Autonomy, and through the benchmarks provided by *LEED Protocol*. The results demonstrated an increase of 5-6% in the rental prices in the case of 'high' daylight and/or 'high' view access, which proves the importance of providing adequate rental leases in the real estate.

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Chapter 2
Norms and Regulations for Daylight

2.1 Introduction

The quantification of daylight is complexand it is frequently reduced to the determination of the Daylight Factor, also from the European Directives. It is still very common in Italy, where it initially focused on school buildings and was only later introduced also for residential buildings. While the European and Italian Directives focus on Daylight Factor and RAI, the introduction of *LEED* globally saw a climate-based approach that was able to increase the value given to daylight in a climate-specific way. The improvement of standards is due to the technological and scientific evolution, as well as a higher awareness of climate change and environmental issues. In this context, daylight can be an essential tool to decrease artificial lighting usage, hence saving energy.

While the European Standards and Directives are aimed at professionals, providing guidelines and recommendations for a good design, Protocols, and Certifications focus on net-zero buildings, environmental issues, and higher quality of life for the occupants of the building, all to be determined by a score assessment.

2.2 Daylight Quantification Approaches

The quantification of daylight is quite a complex matter, which definition also differs according to different professions, as reported by Reinhart, Mardljevic, and Rogers[33]. From the architectural point of view, natural light and the building form influences the indoor environment from the visual, thermal, and psychological point of view[34], while from the energy consumption point of view the combination of daylight and artificial lighting, and the use of automatic controls can reduce the total annual energy consumption. The quantification of daylight can be developed using *static* or *dynamic* daylight performance metrics. At first, the **Weather Dataset** is found, providing data for a full year usually on an hourly basis depending on the setting of the building under study, provided for example by EnergyPlus™[35] Weather (EPW)[36]. The data includes temperature, humidity, cloudiness, precipitation, global and diffuse solar irradiance[37], and wind[38]. Secondly, using the weather dataset, the **sky model** (Perez or Standard general) generates the information for the **daylight calculation method**, depending on the **building geometry**, context, and materials chosen. Finally, the **Daylight Performance Metrics** are defined, including daylight, sunlight, and glare metrics for a selected amount of time and within comfort limits.

The current *static* quantitative performance metrics mostly used in buildings are the **Daylight Factor** (**DF**), the **View Out**, and the **Avoidance of Direct Sunlight**[39]. They are defined as *static* because they provide a result without considering the setting's climate and the Protocols based mainly on the average Daylight Factor are the *ITACA Protocol* and the *Building Regulation of the City of Turin - Allegato Energetico*.

The Daylight Factor is one of the most used (and sometimes only) static metric used for daylight quantification and is based on the internal and external horizontal illuminance under a CIE overcast sky, taking into consideration

33 C.F. Reinhart, Z. Rogers, J. Mardaljevic,(2013), *Dynamic Daylight Performance Metrics for Sustainable Building*, LEUKOS The Journal of the Illuminating Engineering Society of North America, p. 2.

34 M. Ayoub, (2019), *100 Years of daylighting: A chronological review of daylight prediction and calculation methods*, Solar Energy 194 (2019), p. 360.

35 U.S. Department of Energy's (DOE) Building Technologies Office (BTO), *EnergyPlus*, available at https://energyplus.net.

36 M. Ayoub, (2019), *100 Years of daylighting: A chronological review of daylight prediction and calculation methods*, Solar Energy 194 (2019), p. 363.

37 Global and diffuse solar irradiance is the only information used in this context.

38 M. Ayoub, (2019), *100 Years of daylighting: A chronological review of daylight prediction and calculation methods*, Solar Energy 194 (2019), p. 364.

39 C.F. Reinhart, Z. Rogers, J. Mardaljevic,(2013), *Dynamic Daylight Performance Metrics for Sustainable Building*, LEUKOS The Journal of the Illuminating Engineering Society of North America, p. 4.

the type of glazing, the building geometry, the surface properties, and the presence of obstructions, avoiding direct sunlight. The **CIE overcast sky** used for the calculation of the Daylight Factor is considered the worst possible condition where no direct sunlight is present, and where all the other alternatives will always result in a higher Daylight Factor, hence a "*better result*". Often the avoidance of direct sunlight is calculated in parallel to the Daylight Factor, including both orientation and latitude, for avoiding an unnecessary fully-glazed façade, whilst not excluding the setting's climate. Daylight Factor is widely used because capable of providing quick results without complex computation.

The ***Dynamic Daylight Performance Metrics*** are found using specific software for daylight simulations, such as Rhino 7[40] with ClimateStudio[41], capable of considering a whole year, including information also about climate, using hourly data of the annual solar (direct and diffuse) radiation. The criteria obtained by these simulations include, among others, the **spatial Daylight Autonomy** (**$sDA_{300/50\%}$**), the **Useful Daylight Illuminance** (**UDI**), and the **Annual Sunlight Exposure** (**$ASE_{1000/250h}$**), which are included in *LEED Protocol version 4.1/2020* (*Figure 8*).

The spatial Daylight Autonomy ($sDA_{300/50\%}$) is *the percentage of a space that receives a minimum target illuminance of 300 lux for at least 50% of the annual occupied hours.* 55% is the acceptance threshold, and 75% is the preferred result for obtaining sufficient daylight[42].

The Useful Daylight Illuminance (UDI) is *the percentage of the annual occupied timesteps when the illuminance is useful, underlit, or overlit*[43].

The Annual Sunlight Exposure ($ASE_{1000,250h}$) is *the percentage of a space that receives a minimum direct sunlight of 1000 lux for at least 250 hours of the annual occupied hours*[44].

These *dynamic* Climate-Based daylight Modeling (CBDM) metrics depend on location and context with obstructions, façade and openings configuration, building orientation, geometry, and materials, including both temporal and spatial information. The results are calculated on a grid of sensors hourly over the year on daylit hours and in the regularly occupied spaces, with direct normal and diffuse horizontal irradiance[45].

The climate-based daylight modeling approaches (CBDM) provide a wide and complete analysis of daylight, but they tend to be executed once the design phase is outlined already. In the preliminary stages of design, this is seldom used because of time and cost, substituted instead by experience and the rules of thumb[46].

The **daylight rules of thumb (DRT)** do not consider the glazing typology, the climate and sky conditions, nor the building typology, and they are the 2.5 rule, the one-tenth rule, and the 15/30 rule[47]. Their approach is rather

[40] McNeel R. *et al.*, *Rhinoceros 3D*, Version 7, Robert McNeel & Associates, Seattle, WA.

[41] Solemma LLC., *Climate Studio*, USA, available at https://www.solemma.com/cs-trial.

[42] M. Ayoub, (2019), *100 Years of daylighting: A chronological review of daylight prediction and calculation methods*, Solar Energy 194 (2019), p. 370.

[43] *ibidem*, p. 370.

[44] *ibidem*, p. 370.

[45] *ibidem*, p. 368.

[46] R.P. Leslie, L.C. Radetsky, A. M. Smith, (2011), *Conceptual design metrics for daylighting*, Lighting Research and Technology 2012 44:277, p. 278.

[47] K. Mansy, *Daylight Rules-of-Thumb Experimentally Examined*, pp. 1-3.

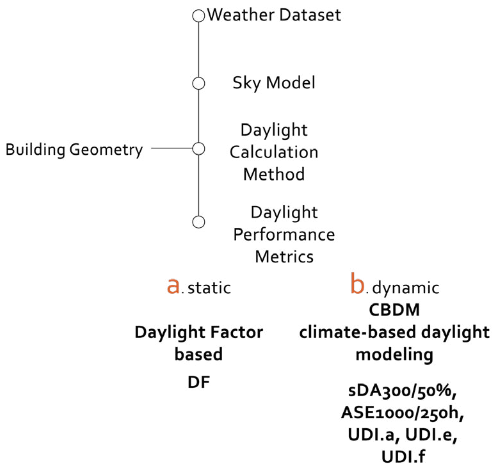

Figure 8 Static and Dynamic Daylight Performance metrics. (Source: Elaboration by the author from M. Ayoub, (2019), *100 Years of daylighting: A chronological review of daylight prediction and calculation methods*, Solar Energy 194 (2019), p. 363).

simplistic and inaccurate in order to obtain a fast result in the early stages of design, saving time, but reaching more of a visual architectural aesthetic through proportions instead of an accurate solution.

The rule of 2.5 states that windows on one side can grant illumination for up to 2.5 times the height of the window head over the workplace (75 cm),[48] when: the glazing is clear, the width of the opening is at least half of the exterior wall length, there is an overcast sky (no direct sunlight), there is high light reflectance indoor, and there is no obstruction to light outside. This will most likely always result in oversizing windows and following many studies, it provides acceptable results only at latitudes of 51° North and South.

The one-tenth rule determines that the minimum Daylight Factor in a space is one-tenth of the glazed window and gross area of the exterior wall ratio, which will most likely result in downsizing windows and inaccuracies due to the use of the minimum Daylight Factor instead of the average.

Finally, the 15/30 rule affirms that the illumination level provided by daylight in an office building is sufficient in the first 15 feet (4.5 meters) from the window, the other 15 feet will get only 50% of the daylight provision, and finally over the 30 feet (9 meters) from the window no daylight will be present. The 15/30 rule underestimates the illumination in the area closer to the window while overestimating the area far away from it. For all these reasons, the rule of thumbs can be taken into consideration for the very early stages of design only as a starting point, but it needs to be later supported and improved by climate-based daylight modeling approaches for a complete and correct analysis.

[48] K. Mansy, *Daylight Rules-of-Thumb Experimentally Examined*, p. 3.

2.3 The Norms in Italy including Daylight

In Italy the following state legislative decrees are present:

- ***Circolare del Ministero dei Lavori pubblici n° 3151 of 22/5/1967*** addressed to subsidized **civil construction**[49]. Among ventilation, heat transmission, and condensation, also natural light is included, with the **Daylight Factor calculation**, defined as the "*ratio of the illuminance of the work surface at a given position to the illuminance that would occur under the identical conditions of time and place, on a horizontal surface exposed outdoors so as to receive light from the entire celestial vault, without direct sunlight"*. Also, the **average Daylight Factor** is defined as the "*ratio of the average illuminance of the enclosed room to the illuminance that would occur, under identical conditions of time and place, on a horizontal surface exposed in the open air so as to receive light from the entire sky vault without direct radiation from the sun"*. The glazing area (transparent surface) can not exceed the value of daylight average coefficient equal or higher to 0,06, found through the relation (1):

$$[\, S_w \,/\, (1\text{-}d_m)\, S \,] \times E \qquad (1),$$

where S_w is the window surface in square meters, d_m is the average coefficient of referral of the inner faces of the walls of the room, S is the surface of walls, E is the daylight coefficient found in the window's barycenter.

- ***Circolare del Ministero dei Lavori pubblici n° 13011 of 22/11/1974*** addressed to **hospital** buildings[50][CM1974]. It provides minimum illuminance levels, from 80 lux on toilets, staircases, and distribution spaces, up to 300 lux in medical rooms. The average Daylight Factor in these cases is between 1% to 3% as depicted in the table below (*Figure 9*).

[49] Circolare del Ministero dei Lavori pubblici del 22 maggio 1967, n° 3151, *Criteri di valutazione delle grandezze atte a rappresentare le proprietà termiche, igrometriche, di ventilazione e di illuminazione nelle costruzioni edilizie*.

[50] Circolare del Ministero dei Lavori pubblici del 22 novembre 1974, n° 13011, *Requisiti fisico-tecnici per le costruzioni edilizie ospedaliere. Proprietà termiche, igrometriche, di ventilazione e di illuminazione*.

- Decreto del Ministero della Sanità of 5/7/1975 addressed to **residential constructions**[51] [DM1975] (*Figure 9*). It provides the minimum height in residential units, at 2,70 meters, reduced to 2,40 for corridors, storage rooms, and toilets. Each inhabitant needs to have at least 14 m^2 and a one-person apartment needs to be at least 28 m^2, 38 m^2 if for two. All the rooms need to have adequate direct daylight, with the exception of toilets, corridors, staircases, and storage rooms. In article 5 of the Decree it is stated:

"per ciascun locale di abitazione, l'ampiezza della finestra deve essere proporzionata in modo da assicurare un valore di fattore di luce diurna medio non inferiore al 2% e comunque la superficie fenestrata apribile non dovrà essere inferiore a 1/8 della superficie del pavimento",

meaning that for each room it must be guaranteed a minimum of **2%** of average Daylight Factor, and the openable window surface must always exceed 1/8 of the floor surface for each room (known as *RAI:* $S_{window,openable} >= 1/8\ S_{floor}$).

- Decreto Ministeriale del Ministero dei Lavori Pubblici of 18/12/1975 addressed to **school** buildings, where indications to guarantee the maximum visual comfort, among good acoustic and thermal conditions, and safety are provided[52]. An adequate illuminance level needs to be reached, depending on the activity, from 100 lux for corridors, distribution, toilets, and storage rooms, 200 lux for classrooms where lectures happen, laboratories, and offices, up to 300 lux[53] in classrooms where drawing, sewing and other similar activities happen. These values need to be guaranteed always under any sky conditions, and for this reason, artificial lighting needs to be combined with natural light, as well as the use of shadow devices to avoid glare. The average Daylight Factor is used and it must be between 0,01 ηm for offices and distribution, 0,02 ηm for gyms and canteens, and finally 0,03 ηm for classrooms.

- Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare (CAM) of 11/10/2017, includes the minimum environmental criteria for the new constructions, restoration, and maintenance of public buildings[54]. Once again, a minimum average Daylight Factor higher than 2% must be guaranteed in all regularly occupied spaces, as well as natural ventilation through openings with a surface of at least 1/8 of the floor's surface.

In addition, the following technical norms are valid:

- *UNI 10840:2007 (2007),* ***Luce e illuminazione - Locali scolastici . Criteri generali per l'illuminazione artificiale e natural****e*, where the average Daylight Factor is

[51] Decreto del Ministero della Sanità del 5 luglio 1975, *Modificazioni alle istruzioni ministeriali 20 giugno 1896 relativamente all'altezza minima ed ai requisiti igienico sanitari dei locali d'abitazione*.

[52] Decreto del Ministero della Sanità del 18 dicembre 1975, *Norme tecniche aggiornate relative all'edilizia scolastica, ivi compresi gli indici di funzionalità didattica, edilizia ed urbanistica, da osservarsi nella esecuzione di opere di edilizia scolastica*.

[53] These illuminance levels refer to the working plane illuminance level, situated at 1,00 m from the floor.

[54] Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare (CAM) of 11/10/2017, *Criteri ambientali minimi per l'affidamento di servizi di progettazione e lavori per la nuova costruzione, ristrutturazione e manutenzione di edifici pubblici.*

better defined, as well as the Daylight Glare Index (DGI) [UNI2007] (*Figure 9*). This norm updates the previous *UNI* of 2000 and aims at guaranteeing the correct illuminance value, combining daylight and artificial lighting.
- UNI EN 15193-1:2007 (2007), Prestazione energetica degli edifici - Requisiti energetici per illuminazione - Parte 1: Specificazioni, Modulo M9.

	DF_m>=1%	DF_m>=2%	DF_m>=3%	DF_m>=4%
Residential sector [DM1975]	---	all spaces	---	---
School sector [UNI2007]	offices, distribution spaces, staircases, toilets	gym, canteen, communal classrooms	classrooms, laboratories	playroom
Hospital sector [CM1974]	offices, distribution spaces, staircases, toilets	gym, canteen	laboratories, patients' rooms, diagnostics	---

Figure 9 Table summing up the general regulation for daylight in the residential, school, and hospital sectors in Italy. (Source: Elaborated by the author from the Norms and Decrees listed above).

2.3.1 The Building Regulation of the City of Turin

In the *Building Regulation of the City of Turin of 2018*[55] sheet 4 focuses on natural light and uses as a calculator the **average Daylight Factor**[56]. The *Energy Code Annex* of 20 March 2006 includes mandatory and voluntary requirements, in order to encourage the application of the standards with a tax reduction[57]. Daylight is included in the **voluntary requirements** only, together with summer shading and winter radiation of the glazed surfaces.
The indoor illuminance is determined:
- by the direct flux from the external primary sources Φ_d (sun and sky vault);
- by the reflected light flux from obstructions and external surfaces Φ_{re} (ground, adjacent buildings);
- by the indirect luminous flux generated by multiple reflections occurring on the interior surfaces of the environment Φ_{ri} (2)[58].

[55] Comune di Torino (2018), *Regolamento edilizio della città di Torino - Allegato energetico - Ambientale*, pp.18-22.

[56] Fattore medio di Luce Diurna (*FLD_M*).

[57] M. Nigra *et al.*, (2021), *'Re-coding' environmental regulation - a new simplified metric for daylighting verification during the window and indoor space design process*, Architectural Engineering and Design Management, p. 3.

[58] Comune di Torino (2018), *Regolamento edilizio della città di Torino - Allegato energetico - Ambientale*, p.47.

$$E_i = E_d + E_{re} + E_{ri} \quad (2).$$

The Daylight Factor is the result of the relation (3):

$$FLD = E_i / E_{eh} \quad (3),$$

with E_i the illuminance of one point in the indoor environment, and E_{eh} the illuminance of an external horizontal plane with no direct sunlight. It is expressed in percentage and it is the result of the contribution to the illuminance of the direct component, and the interior and exterior reflection component. It is, in fact, the sum of the direct component, and all the reflected components (interior and exterior).

All the regularly occupied rooms must have an average Daylight Factor at least equal to or higher than 3%, which can be verified in the design phase as it follows (4):

$$FLD_M = [\,(A_F \times t \times \varepsilon\,) / S_{TOT} \times (1 - r_M)\,] \times \psi \quad (4).$$

For its correct calculation, several coefficients need to be found:

1. *t* is the light transmission of the glass (0,90 if simple clear glass, 0,80 if normal transparent, 0,70 when low-emission glass).
2. A_F is the glass surface and when it is not known it equals 0,75*A_l (where A_l is the gross area of the frame).
3. S_{TOT} is the total surface of the room considered.
4. r_M is the weighted average coefficient of light reflection on indoor surfaces (usually 0,7 for light surfaces).
5. ε is the window factor found as (1 - *sen*α) / 2 where α is the altitude plane angle subtending the obstructed part of the sky (for obstructions placed in front of the window of the room considered). First, the height of the window barycenter is found (h), followed by the height of the obstruction in front of the window (H), and finally, the distance L_A between the obstacle and the window, as shown in *Figure 10*.

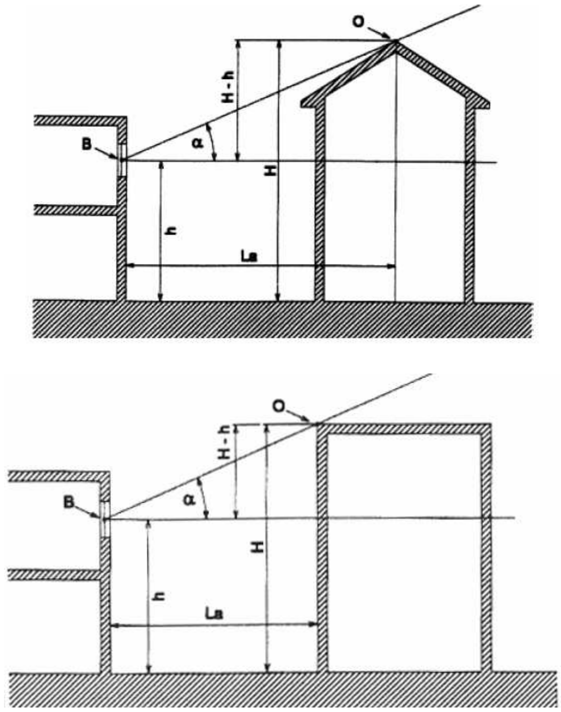

Figure 10 Image depicting the distance and height between the opening considered and the external obstruction. (Source: Comune di Torino (2018), *Regolamento edilizio della città di Torino - Allegato energetico - Ambientale*, p.19, http://www.comune.torino.it/ediliziaprivata/energia/pdf/ae_testo_26022009.pdf)[59].

Once the values are obtained, α is obtained directly with the relation (5):

$$\alpha = (H\text{-}h)/L_a\ [°] \qquad (5),$$

which represents the tangent of the obstruction angle, and finally *ε* can be obtained from the table in *Figure 11*.

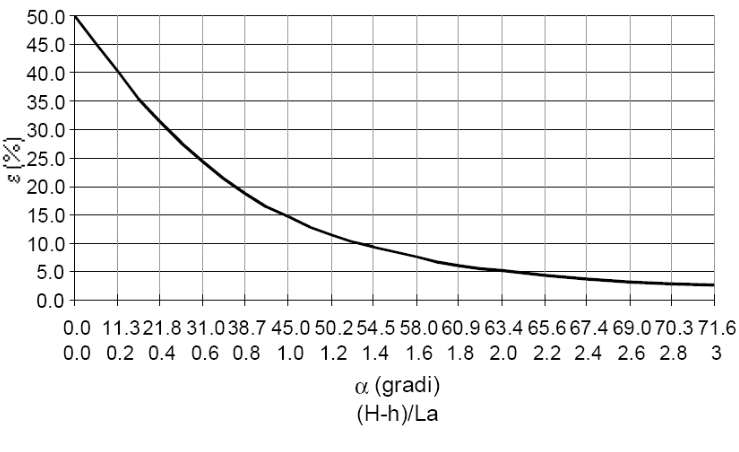

Figure 11 Image providing the *ε* value, once α is known. (Source: Comune di Torino (2018), *Regolamento edilizio della città di Torino - Allegato energetico - Ambientale*, p.20, http://www.comune.torino.it/ediliziaprivata/energia/pdf/ae_testo_26022009.pdf).

6. *ψ* is the reduction window factor coefficient and is found following the indications provided in *Figure 12*, knowing the length, height, and thickness of the window (and their relations hf/p and L/p).

[59] h is the window barycenter B height from the street level; H is the total height of the obstruction in front of the window considered, L_a is the distance between the window and the building's obstruction.

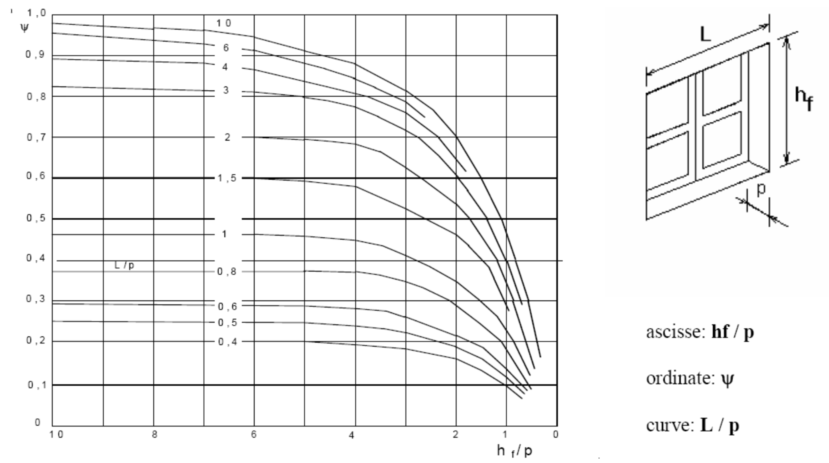

Figure 12 Image providing the ψ value, once α is known. (Source: Comune di Torino (2018), *Regolamento edilizio della città di Torino - Allegato energetico - Ambientale*, p. 22, http://www.comune.torino.it/ediliziaprivata/energia/pdf/ae_testo_26022009.pdf).

When the average Daylight Factor reaches at least 3% it acquires 3 points, when it exceeds 4% it acquires 5 points.
During the operation phase, it is possible to adopt a control methodology using a lux meter on-site. First, the indoor illuminance (E_I) is found in three points at the height of 0,9 meters from the floor and at a distance of 1,50 meters from the wall with openings towards outside, together with the external illuminance (E_E) values on an uncovered horizontal plane without direct sunlight. As a result, the average Daylight Factor is found as (6):

$$FLD_M = E_{IM} / E_{EM} \qquad (6),$$

where E_{IM} is the average of indoor illuminance values and E_{EM} is the average of external illuminance values.
The average Daylight Factor is still widely used, although it has many limits:
- it doesn't consider direct solar radiation;
- it doesn't consider the latitude, the season, or the orientation of the building;
- it doesn't consider the actual sky condition, but instead it only uses the covered sky CIE (the worst case scenario);
- it is independent of the direct sun;
- it doesn't consider movable shading devices;
- and finally it is a static parameter because it is represented by one value for the whole year.

2.3.2 DF vs RAI

In the Building Regulation of the City of Turin it is planned the introduction of a new Index: $RAI_{enhanced}$. RAI has been previously introduced in ***Decreto del Ministero della Sanità of 5/7/1975*** addressed to **residential constructions**[60], as well as in ***Decreto del Ministero dell'Ambiente e della***

[60] Decreto del Ministero della Sanità del 5 luglio 1975, *Modificazioni alle istruzioni ministeriali 20 giugno 1896 relativamente all'altezza minima ed ai requisiti igienico sanitari dei locali d'abitazione*.

Tutela del Territorio e del Mare (CAM) of 11/10/2017.

The ***Ratio Aerial Illuminating*** *RAI* stands for the window area to room area ratio and it is a ventilation-daylight requirement corresponding to the ***window-to-floor ratio*** (*WFR*) (7):

$$RAI: S_{window,openable} \geq 1/8\ S_{floor} \qquad (7),$$

which was introduced for adequate ventilation and for having direct natural light indoor, in the case of regularly occupied spaces, together with 2% average Daylight Factor. RAI itself is not enough according to the regulations, due to its simplicity, but only used together with the average Daylight Factor. In many cases, when reaching the 2% threshold, the 1/8 ratio is easily obtained, which may be a problem to achieve, instead, for older buildings. The most limiting part of RAI is the absence of any context outside of the room geometry (window and floor surfaces). While the ratio could be satisfied, the location of the window could be in the proximity of another construction, hence limiting the actual natural light entering the room.

In the new elaboration of the City Regulation, RAI has been developed as (8)[61]:

$$RAI_{enhanced} >= RAI_{enhanced,\ target} = 0{,}44\ FLD_{m,target} \qquad (8).$$

Where $RAI_{enhanced}$ is found as (9)[62]:

$$RAI_{enhanced} = (S_g / 3{,}2 * S_{floor} + 35{,}6\ ) * T_v * (50 - m_{\alpha i}) \qquad (9),$$

where S_g is the glazing surface, S_{floor} the floor surface, T_v the glazing visible transmittance, and *m* represents the obstructions (0,73 when obstructions ahead, 0,45 when overhangs, 0,55 when both obstructions ahead and overhangs are present). With this update, the obstruction angles are now included, together with the glass transmission, improving the RAI which initially included only the window and floor geometries. This new $RAI_{enhanced}$ wants not to substitute the average Daylight Factor, but instead aims at improving a simple ratio and becoming a mandatory requirement instead of voluntary, to improve its accuracy from the original RAI, while increasing its application to all buildings typologies[63]. The limitations of $RAI_{enhanced}$ are the same as the DF_m, since they both do not consider the orientation, the season, the climate, and the sun paths[64], and the $RAI_{enhanced}$ can be applied only when vertical openings are present.

[61] V.R.M. Lo Verso, (2023), *B4.5b_ ITALIAN Standard and Regulations*, NLITED.

[62] M. Nigra et al., (2021), *'Re-coding' environmental regulation - a new simplified metric for daylighting verification during the window and indoor space design process*, Architectural Engineering and Design Management, p. 7.
[63] *ibidem*, p. 7.
[64] *ibidem*, p. 17.

2.3.3 ITACA Protocol

2.3.3.1 Introduction

ITACA[65] is the *Italian institute for procurement innovation and transparency and environmental compatibility*[66]. UNI published *UNI/PdR 13:2015* first in 2015, and later in 2019, with the technical scientific support of iiSBE[67]. In this document, it is defined a system to assess the environmental sustainability of the buildings with criteria and methods, in order to classify them through a performance score. The most recent update is ***DM of 23 June 2022***, which provides the **rating systems** for determining the compliance with the Minimum Environmental Criteria[68][69].

2.3.3.2 Contents and objectives - UNI/PdR 13:2015

ITACA Protocol[70] aims at classifying residential buildings at the executive level, freshly built or recently renovated, individually, or together with its pertinent external area[71]. The document provides information for points calculation, following three consecutive stages:

1. *characterization*[72]: the building performance for each criterion is quantified through appropriate indicators;
2. *normalization*[73]: the value of each indicator is made dimensionless and is "rescaled" into a normalization interval;
3. *aggregation*[74]: the normalized scores are combined together obtaining the final score.

The structure of the document is as it follows:

- A is for the site selection and design.
- B is for the non-renewable primary energy during the life cycle, the use of renewable energy and eco-compatible materials, drinkable water, and envelope performance.
- C is for CO_{2eq} emissions, solid waste, soil permeability, and heat island effect.
- D is for ventilation and air quality, **D.4.1** is for **daylighting** and acoustic quality.
- E is for efficiency, maintenance, and technical documentation availability.

The criterion D.4.1[75] in the ITACA Protocol is entirely dedicated to Daylight and it focuses on reaching an appropriate daylight level in all regularly occupied spaces, using the **average Daylight Factor** (%).

The Daylight Factor is calculated for each opening, disregarding any

65 Istituto per l'innovazione e trasparenza degli appalti e la compatibilità ambientale.

66 Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), UNI/PdR 13:2015, *Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*.

67 International initiatives for a Sustainable Built Environment

68 UNI Ente Italiano di Normazione (2023), *Sostenibilità ambientale delle costruzioni: un aggiornamento per la UNI/PdR 13*.

69 *Criteri Ambientali Minimi* (CAM)

70 Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), *UNI/PdR 13:2015*, *Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*.

71 *ibidem*, p. 7.

72 *caratterizzazione*.

73 *normalizzazione*.

74 *aggregazione*.

75 Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), UNI/PdR 13:2015, *Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, pp. 81-83.

movable screening device, but considering all fixed shadowing and obstructions. The rooms to be included in the calculation are all regularly occupied spaces, excluding toilets, storage rooms, laundry, corridors, garages, technical rooms, and staircases.

For the **vertical windows**, the Daylight Factor of the window is found as follows (10):

$$Dc_i = (4.13 + 20 \times I_T - 1.36 \times I_{DE}) \times I_O \ [\%] \quad (10),$$

where:

I_T is the transparency index of the environment with homogeneous lighting characteristics [-];

I_{DE} is the depth index of the illuminated area [-];

I_O is the average obstruction index of the environment [-].

The Daylight Factor D_i [%] is found as it follows (11):

$$D_i = D_{ci} \times \tau_{D65} \times k_1 \times k_2 \times k_3 \quad (11),$$

where:

D_{ci} is the Daylight Factor related to the window geometry [%];

τ_{D65} is the hemispheric light transmission factor of the transparent surface (the values can be found in Table C.1a of *UNI EN 15193*) [-];

k_1 is the reduction factor due to the frame[76] [-];

k_2 is the reduction factor due to the presence of dirt on the glass [-];

k_3 is the reduction factor due to non-perpendicular incidence of sunlight [77][-].

For the **horizontal windows** the Daylight Factor related to the window geometry D_i [%] is defined as it follows (12):

$$D_i = D_{ext} \times \tau_{D65} \times k_{obl,1} \times k_{obl,2} \times k_{obl,3} \times (\Sigma A_{Rb} / A_{Rg}) \times \eta_R \ [\%] \quad (12),$$

where:

D_{ext} is the external Daylight Factor [%];

τ_{D65} is the hemispheric light transmission factor of the transparent surface (the values can be found in Table C.1a of *UNI EN 15193*) [-];

$k_{obl,1}$ is the reduction factor due to the frame[78] [-];

$k_{obl,2}$ is the reduction factor due to the presence of dirt on the glass [-];

$k_{obl,3}$ is the reduction factor due to non-perpendicular incidence of sunlight [79][-];

[76] Define the relation between glazing and the total area of the window on the external wall.

[77] Use 0.9 instead of 0.85 as suggested by *UNI 15193*.

[78] Define the relation between glazing and the total area of the window on the external wall.

[79] Use 0.9 instead of 0.85 as suggested by *UNI 15193*.

A_{Rb} is the area of the i-th window compartment [m²];

A_{Rg} is the useful floor area of the room [m²];

η_R is the horizontal window utilization factor [%].

When **multiple windows** in the same room are present it is necessary to first determine geometrically the position and extent of the illuminated area of each window according to C2 and C3 of UNI 15193, then associate each illuminated area with its Daylight Factor $D_{c,fin}$, determine the overlapping zones of the illuminated areas, and eventually associate with these areas the value of the maximum Daylight Factor among the Daylight Factors of the areas that overlap as depicted in *Figure 13*.

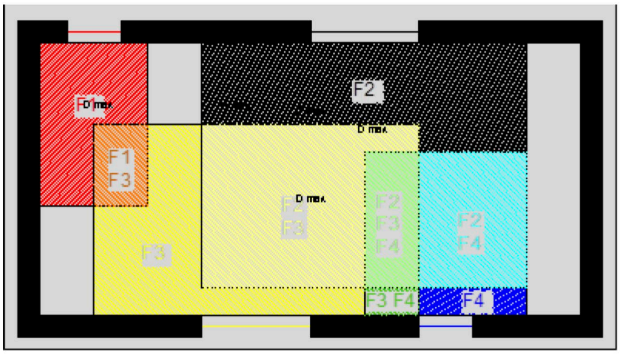

Figure 13 Image depicting the distinct areas illuminated and overlapping. (Source: Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), *UNI/PdR 13:2015, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p. 83, https://www.itaca.org/archivio_documenti/area_sostenibilita/uni_pdr_13_1_2015.pdf).

The last step is the calculation of the weighted average Daylight Factor (D_m) of each window on the lit areas using the formula (13):

$$D_m = \sum (D_i \times F_i) / \sum F_i \qquad (13).$$

When the sum of the sunlit area is below 40% of the useful surface, assign $D_i = 0$ to the remaining areas.

After having collected all the Daylight Factor values of the window, it is possible to execute the weighted average of the Daylight Factor on the areas under study, as it follows (14):

$$D_m = \sum (D_i \times S_u) / \sum S_u \qquad (14),$$

where:

D_i is the Daylight Factor of the i-th room [%];

S_u is the useful floor area of the i-th room [m²].

The value found is then compared with the performance scale benchmarks and the correct score is assigned, following *Figure 14*.

Performance scale Benchmarks	%	Score
Negative	<2.00	-1
Sufficient	2,00	0
Good	2,60	3
Optimal	3,00	5

Figure 14 Table showing benchmark value and relative point assignment. (Source: Re-elaborated by the author from Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), *UNI/PdR 13:2015, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p. 81, https://www.itaca.org/archivio_documenti/area_sostenibilita/uni_pdr_13_1_2015.pdf).

Here it follows the original version of ITACA Protocol (2015 version) in *Figures 15-16-17*.

UNI/PdR 13.1:2015

SCHEDA CRITERIO D.4.1 – ILLUMINAZIONE NATURALE

QUALITÀ AMBIENTALE INDOOR	NUOVA COSTRUZIONE RISTRUTTURAZIONE	D.4.1
Benessere visivo		
Illuminazione naturale		

AREA DI VALUTAZIONE	CATEGORIA
D. Qualità ambientale indoor	D.4 Benessere visivo
ESIGENZA	**PESO DEL CRITERIO**
Assicurare adeguati livelli d'illuminazione naturale in tutti gli spazi primari occupati.	nella categoria / nel sistema completo
INDICATORE DI PRESTAZIONE	**UNITA' DI MISURA**
Fattore medio di luce diurna medio degli ambienti dell'edificio (Dm).	%

SCALA DI PRESTAZIONE

	%	PUNTI
NEGATIVO	<2,00	-1
SUFFICIENTE	2,00	0
BUONO	2,60	3
OTTIMO	3,00	5

Metodo e strumenti di verifica

1. Calcolare, per ogni finestra, il fattore di luce diurna (D) in assenza di schermatura mobile e considerando gli ombreggiamenti fissi, per ciascun tipo di vetro e di locale, secondo la procedura descritta nell'Appendice C della UNI EN 15193.

Nota 1 Il calcolo del Fattore di Luce Diurna (D) si effettua per ciascun ambiente principale dell'edificio illuminato naturalmente ad esclusione di bagni, lavanderie, ripostigli, magazzini, spazi di distribuzione, locali impiantistici, garage, vani scala. Per un calcolo più dettagliato o per casi particolari (es. presenza di più finestre in un unico locale, etc.), si rimanda alle indicazioni contenute nell'Appendice C della UNI EN 15193.

FINESTRE VERTICALI

Calcolare il fattore di luce diurna relativo alla geometria della finestra Dc_i [%] con la seguente formula:

$$Dc_i = (4.13 + 20 \cdot I_T - 1.36 \cdot I_{DE}) \cdot I_O \qquad (1)$$

dove:

I_T = indice di trasparenza dell'ambiente con caratteristiche illuminotecniche omogenee, [-];
I_{DE} = indice di profondità della zona illuminata, [-];
I_O = indice di ostruzione medio dell'ambiente, [-].

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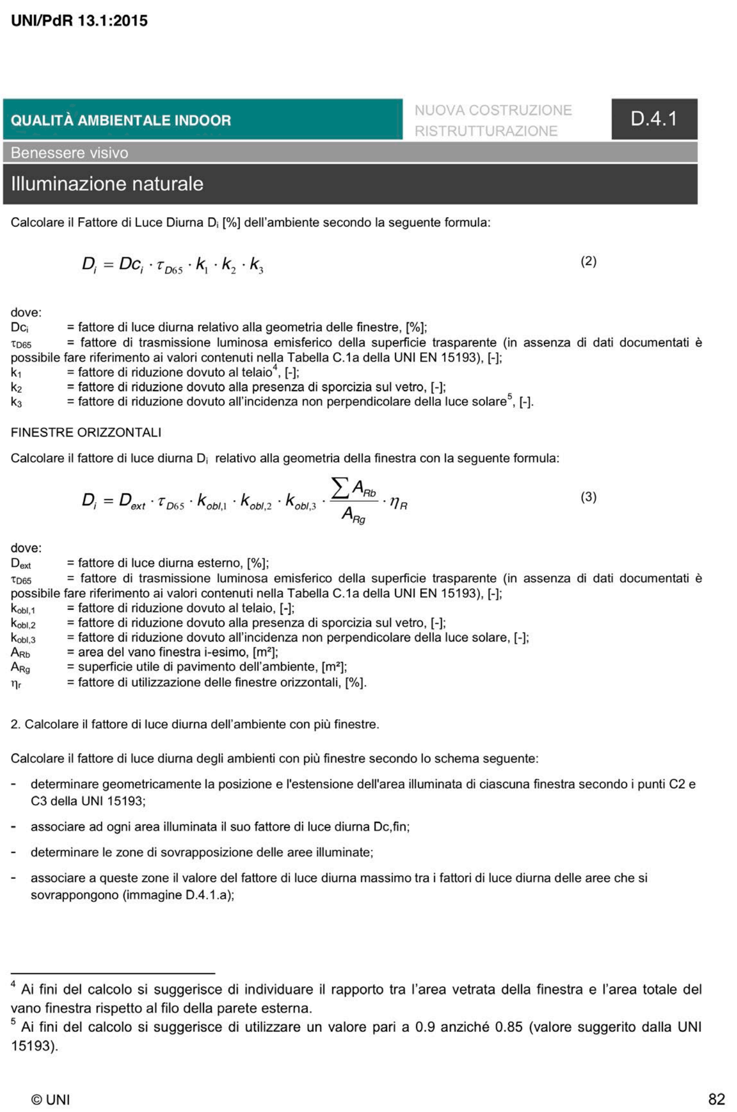
Figure 15 ITACA Protocol. (Source: Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), *UNI/PdR 13:2015, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p. 81, https://www.itaca.org/archivio_documenti/area_sostenibilita/uni_pdr_13_1_2015.pdf).



UNI/PdR 13.1:2015

QUALITÀ AMBIENTALE INDOOR	NUOVA COSTRUZIONE RISTRUTTURAZIONE	D.4.1

Benessere visivo

Illuminazione naturale

Calcolare il Fattore di Luce Diurna D_i [%] dell'ambiente secondo la seguente formula:

$$D_i = Dc_i \cdot \tau_{D65} \cdot k_1 \cdot k_2 \cdot k_3 \qquad (2)$$

dove:
Dc_i = fattore di luce diurna relativo alla geometria delle finestre, [%];
τ_{D65} = fattore di trasmissione luminosa emisferico della superficie trasparente (in assenza di dati documentati è possibile fare riferimento ai valori contenuti nella Tabella C.1a della UNI EN 15193), [-];
k_1 = fattore di riduzione dovuto al telaio[4], [-];
k_2 = fattore di riduzione dovuto alla presenza di sporcizia sul vetro, [-];
k_3 = fattore di riduzione dovuto all'incidenza non perpendicolare della luce solare[5], [-].

FINESTRE ORIZZONTALI

Calcolare il fattore di luce diurna D_i relativo alla geometria della finestra con la seguente formula:

$$D_i = D_{ext} \cdot \tau_{D65} \cdot k_{obl,1} \cdot k_{obl,2} \cdot k_{obl,3} \cdot \frac{\sum A_{Rb}}{A_{Rg}} \cdot \eta_R \qquad (3)$$

dove:
D_{ext} = fattore di luce diurna esterno, [%];
τ_{D65} = fattore di trasmissione luminosa emisferico della superficie trasparente (in assenza di dati documentati è possibile fare riferimento ai valori contenuti nella Tabella C.1a della UNI EN 15193), [-];
$k_{obl,1}$ = fattore di riduzione dovuto al telaio, [-];
$k_{obl,2}$ = fattore di riduzione dovuto alla presenza di sporcizia sul vetro, [-];
$k_{obl,3}$ = fattore di riduzione dovuto all'incidenza non perpendicolare della luce solare, [-];
A_{Rb} = area del vano finestra i-esimo, [m²];
A_{Rg} = superficie utile di pavimento dell'ambiente, [m²];
η_r = fattore di utilizzazione delle finestre orizzontali, [%].

2. Calcolare il fattore di luce diurna dell'ambiente con più finestre.

Calcolare il fattore di luce diurna degli ambienti con più finestre secondo lo schema seguente:

- determinare geometricamente la posizione e l'estensione dell'area illuminata di ciascuna finestra secondo i punti C2 e C3 della UNI 15193;
- associare ad ogni area illuminata il suo fattore di luce diurna Dc,fin;
- determinare le zone di sovrapposizione delle aree illuminate;
- associare a queste zone il valore del fattore di luce diurna massimo tra i fattori di luce diurna delle aree che si sovrappongono (immagine D.4.1.a);

[4] Ai fini del calcolo si suggerisce di individuare il rapporto tra l'area vetrata della finestra e l'area totale del vano finestra rispetto al filo della parete esterna.
[5] Ai fini del calcolo si suggerisce di utilizzare un valore pari a 0.9 anziché 0.85 (valore suggerito dalla UNI 15193).

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Figure 16 ITACA Protocol. (Source: Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), *UNI/PdR 13:2015, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p. 82, https://www.itaca.org/archivio_documenti/area_sostenibilita/uni_pdr_13_1_2015.pdf).

UNI/PdR 13.1:2015

QUALITÀ AMBIENTALE INDOOR	NUOVA COSTRUZIONE RISTRUTTURAZIONE	D.4.1
Benessere visivo		
Illuminazione naturale		

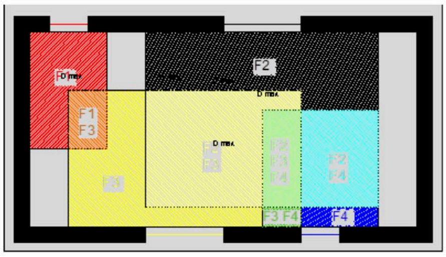

Immagine D.4.1.a

- calcolare il fattore di luce diurna dell'ambiente come media pesata dei fattori D di ciascuna finestra sulle rispettive aree illuminate:

$$D_m = \frac{\sum(D_i \cdot F_i)}{\sum F_i}$$

Nota 2 Qualora la somma delle superfici delle aree illuminate sia < 40% della superficie utile dell'ambiente interessato assegnare all'ambiente i D_i=0, indipendentemente dal valore del fattore D.

2. Calcolare il fattore medio di luce diurna medio degli ambienti dell'edificio eseguendo la media dei fattori calcolati per ciascun locale pesata sulla superficie dei locali stessi.

Calcolare il valore D_m dell'edificio come media pesata dei valori D dei singoli ambienti sulle relative superfici dei locali:

$$D_m = \frac{\sum(D_i \cdot S_u)}{\sum S_u} \qquad (4)$$

dove:
D_i = fattore di luce diurna dell'ambiente i-esimo, [%];
S_u = superficie utile di pavimento dell'ambiente i-esimo, [m²].

3. Confrontare il valore calcolato con i benchmark della scala di prestazione e attribuire il punteggio.

Il punteggio da attribuire al criterio si ricava per interpolazione lineare rispetto ai valori della scala di prestazione.

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Figure 17 ITACA Protocol. (Source: Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2015), *UNI/PdR 13:2015, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p. 83, https://www.itaca.org/archivio_documenti/area_sostenibilita/uni_pdr_13_1_2015.pdf).

2.3.3.3 Contents and objectives - UNI/PdR 13:2023

The latest document in public consultation[80] includes three segments:
- *UNI/PdR 13.0:2023* for the general introduction and the methodology of performance point assignment;
- *UNI/PdR 13.1:2023* for the residential sector;
- *UNI/PdR 13.2:2023* for all the other sectors.

Section D.3 contains the Visual Comfort, with segment D.3.2 as ***Sufficienza della Luce Naturale***[81]. The objective is to reach an adequate level of natural light for guaranteeing visual comfort and reducing the energy usage for artificial lighting, through the introduction of a new index Z_m, representing the level of natural light.

1. The first step is the calculation of the average Daylight Factor following

[80] It is still not published definitively, but will be during the year 2023.

[81] *Sufficiency of Natural Light.*

the *UNI 15193-1* for all the regularly occupied spaces. The reference plane for its calculation is 85 cm from the floor surface, taking into account 50% and 95% of each room's surface.

2. Once the values have been found, each room's result is verified with the Z index as in *Figure 18* for the vertical windows, and *Figure 19* for the horizontal ones, referred to *UNI EN 17037:2022*.

Level of natural light sufficiency	**Requisites of average Daylight Factor**		**Category Index Z_i**
Insufficient	<1,6% in at least 50% of the room's surface	<0,5% in at least 95% of the room's surface	-1
Minimum	≥1,6% in at least 50% of the room's surface	≥0,5% in at least 95% of the room's surface	0
Average	≥2,6% in at least 50% of the room's surface	≥1,6% in at least 95% of the room's surface	3
High	>3,9% in at least 50% of the room's surface	≥2,6% in at least 95% of the room's surface	5

Figure 18 Image depicting the category index Z in vertical windows. (Source: Re-elaborated by the author from Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2023), *UNI/PdR 13:2023, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, pp.81-82, https://www.uni.com/wp-content/uploads/UNI_PdR_13-1_2023_residenziale_consultazione_pubblica_20230522.pdf).

Level of natural light sufficiency	**Requisites of average Daylight Factor**		**Category Index Z_i**
Insufficient	<1,0% in at least 50% of the room's surface	<0,3% in at least 95% of the room's surface	-1
Minimum	≥ 1,0% in at least 50% of the room's surface	≥ 0,3% in at least 95% of the room's surface	0
Average	≥ 1,6% in at least 50% of the room's surface	≥1,0% in at least 95% of the room's surface	3
High	> 2,4% in at least 50% of the room's surface	≥1,6% in at least 95% of the room's surface	5

Figure 19 Image depicting the category index Z in horizontal windows. (Source: Re-elaborated by the author from Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2023), *UNI/PdR 13:2023, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p. 82, https://www.uni.com/wp-content/uploads/UNI_PdR_13-1_2023_residenziale_consultazione_pubblica_20230522.pdf).

3. The indicator Z_m can be found with the formula (15):

$$Z_m = \sum Z_i \times S_{u,j} / \sum S_{u,j} \ [-] \qquad (15)$$

where Z_i is the category index of the i-th room and $S_{u,j}$ is the regularly occupied surface of the i-th room in m^2.

4. The indicator's result obtained can be compared to the benchmark

scale and the adequate points are attributes as reported in *Figure 20*.

Performance scale Benchmarks	Index Value	Score
Negative	-1	-1
Sufficient	0	0
Good	3	3
Optimal	5	5

Figure 20 Image depicting the benchmark values and the points that can be attributed. (Source: Re-elaborated by the author from Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale ITACA (2023), *UNI/PdR 13:2023, Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità - Edifici residenziali*, p.81, https://www.uni.com/wp-content/uploads/UNI_PdR_13-1_2023_residenziale_consultazione_pubblica_20230522.pdf).

2.4 The European Norms and Regulations

2.4.1 Energy Performance of Building Directives (EPBD)

2.4.1.1 Introduction to Energy Performance Building Directives

The **Energy Performance of Buildings Directives** (EPBD) are managed by the European Committee for Standardisation (CEN), which elaborates standards for common grounds in all of the European Union. Buildings are responsible for 40% of the European Union's energy consumption and 36% of the energy-related greenhouse gas emissions (see *Figure 21*)[82]. About 35% of the buildings are over 50 years old and 75% are energy inefficient. In comparison, only 1% is being renovated every year. Seeing this data, it is obviously not enough and action needs to take place. In Europe's GDP the construction sector sum up to 9% and provides 18 million jobs.

[82] European Commission (2021), *Factsheet - Energy Performance of Buildings*, Brussels.

Figure 21 Building and energy relations in the EU. (Source: Re-elaborated by the author from European Commission (2021), *Factsheet - Energy Performance of Buildings*, Brussels, https://ec.europa.eu/commission/presscorner/detail/en/fs_21_6691).

The Energy Performance of Building Directive was first published in 2002 as ***Directive 2002/91/EC*** (16 December 2002)[83] and was last revised in 2021[84]. The European Council of March 2007 reaffirmed the importance of targeting a 20% share of energy from renewable resources alone by 2020[85], but as time passed it was clear the goals set could not be reached on time. Before 2021, in 2010 has been established the Energy Performance of Buildings ***Directive 2010/31/EU***[86], followed by the *Energy Efficiency Directive 2012/27/EU*, and ***Directive 2018/844/EU*** of 2018 (*Figure 22*).

● ***Directive 2002/91/EC***

●● ***Directive 2010/31/EU***

●●● ***Directive 2018/844/EU***

Figure 22 EPB Directives. (Source: Elaborated by the author).

As a remedy to the delayed goals, the *Energy Efficiency Plan of 2011*, aimed at even more stringent measures for reducing energy consumption by 20% by 2020 and promoting high energy efficiency, and achieving zero-emission electricity production and decarbonized building stock by the year 2050.

The aim is to reach the building and renovation goals set out in the *European Green Deal*[87], as to reduce energy consumption and face environmental issues, as well as improve the quality of humans bringing higher indoor quality levels, and providing *green jobs*. Since buildings account for up to 40% of the total energy consumed in the European Union, with the projection of expansion in the future years, actions need to take place, favoring renewable resources for reducing energy consumption and diminishing greenhouse gas emissions[88].

All the Directives comply with the ***Kyoto Protocol*** signed by the *United Nations Framework Convention on Climate Change of 1997*[89].

The protocol aims at:

- reducing greenhouse gas emissions in order to stop the temperature rise above 2°C;

- promoting the security of energy supply by shifting to renewable

[83] *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings*, Official Journal of the European Union, L 001, 04/01/2003 pp.65-71, Brussels.

[84] A new directive revision is expected to be published in 2023.

[85] European Commission, Energy performance of building directive.

[86] *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Official Journal of the European Union, L 153/13, Strasbourg.

[87] European Commission, *Energy performance of building directive*.

[88] *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Official Journal of the European Union, L 153/13, Strasbourg.

[89] European Commission, *Energy performance of building directive*.

sources;
- developing technologically and creating new employment opportunities in less developed rural areas.

2.4.1.2 The Directive of 2018 (Directive 2018/844/EU) and the aftermath

The Directive of 2018[90] introduced new elements for improving the number of **building renovations** in order to achieve the pre-fixed goals. In October 2020 the *Renovation Wave* strategy was presented by the Commission, as a way to double the annual energy renovations of buildings by 2030.

The revised ***Energy Performance of Buildings Directive*** was proposed in December (COM(2021) 802 final) and states that:
- as of 2030 all new buildings must be **zero-emission**, while new public buildings must be zero-emission within 2027;
- the worst-performing 15% of the EU building stock must be renovated from G to F class by 2030 and to E class by year 2033;
- the *Energy Performance Certificate* is mandatory also for all buildings being renovated and the rented properties, as well as all public buildings;
- all units for sale must have an energy performance certificate with class and indicator in the advertisement;
- it is necessary to provide infrastructure for sustainable mobility (bicycle and electric car).

This proposed directive enhances, even more, the use of renewables, as well as circularity and energy efficiency in our buildings. It rises the target of renewables up to 40% in the energy mix and strengthened the previous energy efficiency directive rising to 39% for the primary energy consumption and 36% for the final energy consumption (+9%)[91].

The Energy Performance of a building differs depending on the nation and region where it is set. It includes one full year for including heating and cooling seasons, as well as information about thermal characteristics, HVAC systems, energy from renewable resources usage, passive heating and cooling elements, shading devices, indoor air quality, **natural light**, and the design layout of the building. All State Members of the Union must focus on ensuring minimum energy performance requirements for buildings for achieving cost-optimal levels, using a comparative methodology framework.

ANNEX I of the EPB Directive presents the common general framework for the calculation of the Energy Performance of buildings[92]. In Point 4 a

[90] *Directive 2018/844/EU of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency*, Official Journal of the European Union, L 156/75, Strasbourg.

[91] European Commission (2021), *Factsheet - Energy Performance of Buildings*, Brussels.

[92] *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Official Journal of the European Union, L 153/13, Strasbourg.

list of aspects that have a positive influence on the final result is taken into account and are:
- sun exposure, active solar systems, and other heating and electrical systems based on energy from renewable resources;
- electricity produced by cogeneration;
- district or block heating and cooling systems;
- **natural lighting**.

2.4.1.3 EN 15193-1:2017 Energy Performance of Buildings - Energy Requirements for Lighting

The *European Committee for Standardization* (CEN) developed a few standards with the EPBD's requirements, which *EN 15193-1:2017* is part of and used for determining the lighting energy consumption[93]. This Standard contains information about the technical calculation methods for the internal lighting loads and the integration of artificial lighting into daylighting during the design phase, as for improving the efficiency of daylight and the reduction of energy consumption. In *Decreto Ministeriale of 26 June 2009 "Linee guida nazionali per la certificazione energetica degli edifici"*, it is included the national guidelines for determining the global performance of the building EP_{gl}, which is found as (16):

$$EP_{gl} = EP_h + EP_{dhw} + EP_c + EP_l \qquad (16),$$

where EP_h is the heating performance index, EP_{dhw} is the domestic hot water index, EP_c is the conditioning index, and finally EP_l is the lighting index.
EP_l aims at defining the electric lighting energy consumed monthly or annually, considering, when available, the presence of daylight, as well as considering the occupied time only. First, the artificial lighting electrical power is calculated. Secondly, the daylight value on a monthly, annual, or even hourly level is found. The annual value obtained is referred to as **LENI** (***Lighting Energy Numerical Indicator***)(17). LENI is the net energy demand for lighting and is found as follows:

$$LENI = W_t / A = (W_{L,t} + W_{P,t}) / A \text{ [kWh / m}^2\text{ year]} \qquad (17),$$

where W_t is the total annual energy consumption for lighting in kWh/y, A is the useful surface, $W_{L,t}$ is the total energy consumption estimated for artificial lighting over time t, $W_{P,t}$ is the standby energy over time t. $W_{P,t}$ is

93 CEN (Comité Européen de Normalisation) (2018), *European Standard EN 15193-1:2018, Energy Performance of buildings. Energy requirements for lighting - Part 1: Specifications*, Brussels.

the result of the sum of default standby energy for charging emergency batteries (1.0 [kWh/m²y]) and the default energy consumed by automatic control systems (1.5 [kWh/m²y]).
The total necessary energy for the artificial lighting of the building over the time *t* is given by (18):

$$W_{L,t}=\sum(P_n/1000)\, F_C\, F_O\, (F_D\, t_D + t_N) \quad [\mathrm{kWh/t}] \qquad (18),$$

where $W_{L,t}$ is the sum of all the energy consumed in the different zones of the building, P_n is the total installed power for artificial lighting in each zone [W], t_D are the operation hours in presence of daylight during the regularly occupied time [h], t_N are the operation hours in absence of daylight during the occupied time [h], F_C is the constant illuminance factor [-], F_O is the occupancy dependent factor which considers the actual occupied space over the total [-], and finally F_D is the daylight dependent factor [-].
EP_l can also be found through the relation (19):

$$EP_l = LENI/\eta_{el} \qquad (19),$$

where η_{el} is the national average efficiency of the National Electric Power System. LENI calculation indications are included in the norm *EN15193:2007 Energy performance of buildings. Energy requirements for lighting.*[94] This calculation is very complex due to multiple factors:
- the dynamicity of natural light;
- the effective occupancy of spaces;
- the interaction between humans occupying the space and the control systems.

In *EN15193-1:2017*[95] the **Expenditure Factor e_L** (system efficiency factor) is introduced, together with the **Daylight Supply Factor $F_{D,S}$**. For the $F_{D,S}$ calculation it is necessary to know all the following information:
- the latitude (°);
- the climatic parameter (**luminous exposure**), which in the case of Turin equals 0,43;
- the orientation (N, E, W, S);
- the movable screening systems, when present;
- the average illuminance range (*E* between 100 and 1000 lx);
- the control systems for lighting (occupancy sensors, photo-dimming sensors).

94 CEN (Comité Européen de Normalisation) (2007), *European Standard EN 15193:2007, Energy Performance of buildings. Energy requirements for lighting*, Brussels.

95 CEN (Comité Européen de Normalisation) (2017), *European Standard EN 15193-1:2017, Energy Performance of buildings. Energy requirements for lighting - Part 1: Specifications, Module M9*, Brussels.

The classification relies on the Daylight Factor, which result depends on the room and opening geometries, the overhangs or any other external obstruction, as well as the glass light transmittance and the correction factors such as dirt on the glazing, and oblique light incidence. Each workplace has a relative luminous exposure which is the **energy-saving potential** attributed to daylight.

2.4.2 EN17037:2018 - Daylight in Buildings

UNI EN 17037[96] is a European Standard approved by *CEN*[97] on 29 July 2018 and published in December 2018. It was later translated into Italian and became part of the Italian norm on 21 February 2019.

2.4.2.1 Contents and Objectives

The norm contains indications related to daylighting in indoor spaces, glare limitations, and the view out, with a climate-based approach. Appendix A contains General Recommendations, Appendix B Daylight Provision, Appendix C View Out Valuation, Appendix D Exposure to Sunlight, and Appendix E Glare Protection (*Figure 23*).

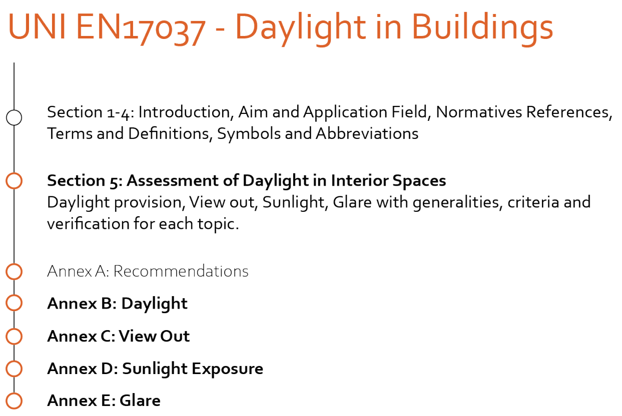

Figure 23 EN17037:2018 Structure. (Source: Elaborated by the author).

The aim of this norm is to obtain elements in order to guarantee adequate daylighting in indoor environments through proper calculations and verifications, as well as providing an adequate view out, referring to all spaces to be occupied by people for a prolonged time span. It included indications about glare avoidance.

96 CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels.

97 Comité Européen de Normalisation, Brussels.

2.4.2.2 Introduction

Natural light is an indispensable tool to counterbalance with electric lighting. Daylight is dynamic, it changes with the season, the climate, the surroundings, and the hour, and it varies in color rendering. It also depends on the obstructions and on the indoor organization. The openings guarantee a view out with different qualities and, while contributing to the well-being of humans, also guarantee access to natural daylight.
The norm is used to reach optimal results in lighting through natural light and to improve view-out quality, glare protection, and sunlight exposure.

2.4.2.3 Indoor Daylighting Valuation

2.4.2.3.1 Daylighting

Every indoor space should be able to guarantee enough daylighting during the whole year, taking into consideration all the setting casualties, such as external obstructions, glazing transmission, walls and ceilings, and roofs thicknesses, furniture, surfaces' reflection factor, and reduction factors for glazing transmission due to dirt.
This is guaranteed when at least half of the hours are daylit, referring to a plane fraction in an indoor space, situated at a height of 0,85 m.
The target level of daylighting for the following cases should always be at least a minimum and are expressed as spatial illuminance (*sE*). The target levels of daylighting for vertical, inclined, and horizontal openings are as follows (*Figures 24-25*).

Recommendation Level for vertical and inclined daylight opening	Target Illuminance E_T (lux)	Target level of space fraction $F_{plane,\%}$	Min Target Illuminance E_{TM} (lux)	Min Target level of space fraction $F_{plane,\%}$	Fraction of daylight hours $F_{time,\%}$
Minimum	300 lux	50%	100 lux	95%	50%
Medium	500 lux	50%	300 lux	95%	50%
High	750 lux	50%	500 lux	95%	50%

Figure 24 Table with recommendation levels of daylighting for vertical and inclined opening. (Source: Re-elaborated by the author from CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels, p.10).

Recommendation Level for horizontal daylight opening	Target Illuminance E_T(lux)	Target level of space fraction $F_{plane,\%}$	Fraction of daylight hours $F_{time,\%}$
Minimum	300 lux	95%	50%
Medium	500 lux	95%	50%
High	750 lux	95%	50%

Figure 25 Table with recommendation levels of daylighting for horizontal opening. (Source: Re-elaborated by the author from CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels, p.11).

These recommendations can also be expressed in Daylight Factors (*D*), referring to the reference illuminance level E_T (lx) and to the recommended minimum reference of illuminance E_{TM} (lx). Since the setting of the study is Italy, the *D* values for Italy are as follows (*Figure 26*).

Nation	**Capital**	**Latitude (°)**	**Median External Diffuse Illuminance** $E_{v,d,med}$	***D* to exceed 100 lux**	***D* to exceed 300 lux**	***D* to exceed 500 lux**	***D* to exceed 750 lux**
Italy	Rome	41,80	19 200	0,6%	1,9%	3,2%	3,9%

Figure 26 Table representing DT (Target Daylight Factor) values when they overcome 100, 300, 500 and 700 lux for a fraction of the daylight hours. (Source: Re-elaborated by the author from CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels, p.12).

The normative includes all data of all capitals of the EU, setting the minimum requirements of Daylight Factors depending on the level of illuminance aimed and with a climate-based approach, with geographic distinctions.

2.4.2.3.2 Daylight Calculation Methods

Daylight can be calculated as:

- calculating the Daylight Factor on the reference plane (*Method 1*);
- calculating daylight on the reference plane taking into account the **climate data** and an adequate temporal span (*Method 2*).

For both methods, it is necessary to determine the grid of points on the reference plane (0,85 m from the floor) to calculate the Daylight Factor, where the cells approximately create squares, with ratios between 0,5 and 2.

The number of points needed is given by the ratio between the longest side of the reference plane, and the maximum dimension of the cells. The area of the grid should be 0,5 m from the walls.

For the calculation methods, **reflection factors** need to be specified. When they are not provided, the recommended values are as follows and always must be declared, and if not followed must be justified:

- for the roofs, the values are between 0,7 and 0,9;
- for the interior walls between 0,5 and 0,8;

- for the floors, the values are between 0,2 and 0,4;
- for the external walls between 0,2 and 0,4;
- for the external terrain 0,2.

Generally, for the floors 0,2 of the reflection factor is used, 0,5 for the walls, and 0,7 for the ceiling.

Method 1 - Daylight Factor

Method 1 assumes a constant relation between internal and exterior illuminance. The Daylight Factors in space should be calculated by means of the grid of points on the reference plane, in a day of cloudy covered sky[98]. The Daylight Factors found should always equal or exceed the reference values of D_T and D_{TM}.

D_T (%) is the **target Daylight Factor** to be exceeded for more than half of daylight on 50% of the reference plane. In other words, it is the ratio between the illuminance level requested, such as 300 lux when talking about the housing sector, and $E_{v,d,med}$. $E_{v,d,med}$ is the median horizontal diffuse illuminance from the sky obtained by half of the natural light hours on the Earth over the year (2 190 hours), which is a value depending on the location (19 200 for Rome, Italy). The result would be 1,56% and this value should be achieved by 50% of the relevant floor area, which is the area closer to the opening and it is found as follows (20):

$$D_T = \textit{illuminance level} / E_{v,d,med} = (300\ lx / E_{v,d,med}) \times 100\ [\%] \quad (20).$$

D_{TM} is the **minimum reference Daylight Factor** to exceed for more than half of the daylight hours on 95% of the space. It is found with the ratio between the illuminance value and $E_{v,d,med}$. The minimum target Daylight Factor, instead, is the relation between the minimum of 100 lux and the external illuminance, in the case of Rome it is 0,52%, and this value should be obtained by at least 95% of the area under study, hence considering also the darkest area of the room more further away from the opening.

Method 2 - Illuminance Level

Daylight calculation with this method is more detailed, considering the illuminance from daylight for a typical year and under specific climatic and weather conditions, appropriate for the setting. Daylight is in this way directly determined by the illuminance levels on the reference plane. Also, any type of mobile screening, such as curtains, needs to be inserted dynamically in the calculation through adequate software. When the reference value is 300 lux, at least 50% of the reference plane must be hit by daylight for 2190 hours (half of the total daylight hours).

[98] As stated by *ISO 15469:2004, Spatial distribution of daylight - CIE Standard general sky.*

Regarding the minimum 100 lux, on 95% of the reference plane, there must be daylight for 2190 hours, in all the cases of vertical, horizontal, and oblique openings.

The climate data to be used for this method contain 8760 values divided by hour and in relation to the diffuse illuminance.

The verification can be done through software, where it is needed the surrounding with all the obstructions, the reflection factor of all the surfaces, and the glass transmission values, in cloudy covered sky conditions. The verification can also happen in person using lux-meters in real life and using a grid of points on the reference plane. The values found are then confronted with the measurements taken in the real space, when possible, and still taking into consideration the limitation that could cause.

In practical terms, illuminance levels in real life are measured both indoors and outdoors at the same time, and both geometrical and surface properties are defined. Both properties are then confronted between prediction and real space.

2.4.2.3.3 View Out

The view out is the link towards the outside and gives information about the hour, the climate, the surroundings, and the weather, which can serve as a relief for long indoor stays. It can be evaluated in reference points representing different positions where people can be. A view has three layers: one **sky level**, one **landscape level** (which can give information about buildings, nature, and the horizon), and one **terrain level** (which gives information about activities). These layers need to be seen for at least 75% of the used area.

The view-out quality depends on the size of the opening, the angle of vision, the number of layers, the quality of the information provided by the view, and on the distance from the external view. In order to ensure a good view out quality the glazing material should not distort the view and be of a neutral color, the opening should guarantee a horizontal angle and the area should have a minimum of layers. A natural view is usually preferred over an urban view, a varied and dynamic view over a monotonous view.

The minimum level of view out has at least the landscape layer (nature or urban), giving information about the exterior, followed by the average level with two layers visible, and finally the high level with all layers visible. The view-out classification also includes the distance from the external view and the angle of horizontal vision, where the higher the better, in order to guarantee a wide and distant view (*Figure 27*).

Figure 27 Table showing the recommendation levels and information about the distance of the view, angle of vision, and the number of layers of the view. (Source: Re-elaborated by the author from CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels, p.14).

Recommendation Level for the view-out	Horizontal sight angle	Distance of the view	Numbers of layers from at least 75% of the area
Minimum	≥ 14°	≥ 6,0 m	At least the landscape layer
Average	≥ 28°	≥ 20,0 m	Landscape layer + 1 other layer
High	≥ 54°	≥ 50,0 m	All layers

Along with all the above information to take into consideration, the quality of the view is also influenced by the aesthetic value of the objects in the view and the view composition. The aesthetic of the view is related to the age, the complexity, and the maintenance, while the composition can be determined by the photographic composition from the different viewpoints. This additional subjective classification is composed by:
- the minimum level when the hour, the weather, and the setting information is provided;
- the average level when additional natural landscape information is provided;
- the high level when all information above is included.

The view width of a minimum level should be at least 14° of horizontal vision, from the reference point that can be anywhere within the indoor space. When multiple façades in the same space have openings, one should be classified at least at the minimum level, and the distance between the façade and the further point from it, should in this case be a diagonal line. When the opening is above eye-level the *xy* projection perpendicular to the human eye is considered. When there is no opening towards the outside, the opening towards inner courtyards with social interactions and greenery can be used.

With the simplified verification method, the width view valuation is done excluding the line of the sky and the line of the ground. To reach the minimum value, the layers to be seen by 75% of the space should be at least the landscape (nature or urban). Depending on the position considered, more or less layers can be visible. As a reference point for the human eye, 1,2 m when seated or 1,7 m when standing heights are used. In *Figure 28* ***e*** represents the eye height, in this case, a person seated so at 1,2 meters height, *A* is the sky, *B* is the landscape/cityscape, *C* is the ground. a_1, a_2, a_3 are the visible layers, and *b* and *c* respectively are no sky and no ground.

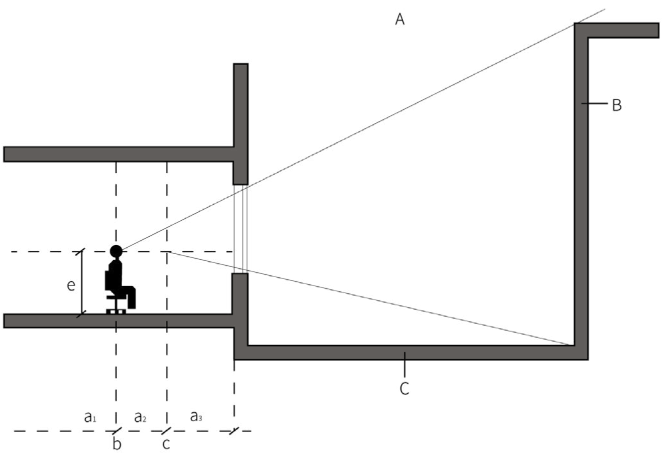

Figure 28 Transversal section for simplified verification. (Source: Re-elaborated by the author from CEN (Comité Européen de Normalisation) (2018), *European Standard EN 17037:2018, Daylight in buildings*, Brussels, p.25).

The advanced verification method is by projection, used in the case of complex shapes or multiple openings. It uses a 180 equidistant degrees projection using a photographic camera in the case of a realized project, or via an informatic software or manual drawing when in case of design stage.

2.4.2.3.4 Sunlight Exposure

Sunlight exposure consists in verifying when the sun is visible through the sky on the date chosen and for how many hours it is visible. Most indoor spaces should guarantee a proper amount of hours to be in sunlight[99], as to contribute to humans' well-being. Sunlight exposure cannot exceed a certain amount, provoking discomfort and glare, but also cannot be reduced to the minimum. The sunlight exposure access in the design stage is used to choose a proper building volume, design the façade, and the openings, as well as the interior organization according to the orientation, and the addition of screening devices when needed. One of the important features of sunlight exposure is the help in reducing energy consumption for heating.

The verification is done in a sunlit area in correspondence to a point, chosen manually or via software and sun trajectory diagrams, or in person through geometrical or photographic measurements.

The recommendation for sunlight exposure in data between the 1st of February and the 21st of March on a cloudless day is:

- minimum with 1,5 hours;
- average with 3,0 hours;
- and high with 4,0 hours.

The valuation needs to take place for each of the openings from a reference point *P* set on the center of the interior side of the opening itself. The reference point is a minimum of 1,2 m above the floor and 0,3

99 Considering one cloudless day during the year.

m over the window sill, if present. The result varies depending on the obstructions of the surroundings and on the opening shape.

Method 1 - Software and sun trajectory diagrams

The software lets us generate external images from the reference point *P*, from the opening for daylight. For example, with software capable of producing a 180° image, the obstruction-free sky is compared to the circular Sun trajectories.

Method 2 - Manual geometrical constructions

The method requires identifying critical azimuth angles and elevation ones, for determining when a reference point is sunlit. When the Sun elevation values are higher than the obstructions elevation values, the reference point is sunlit.

According to the location, sunlight conditions differ. The correct room orientation and openings design need to guarantee the necessary time to be sunlit. The verification can be done in person with a photographic camera with a wide 180° angle, in order to overlap the sun diagram.

2.4.2.3.5 Glare Protection

Glare needs to be avoided since it provokes discomfort in the human eye, in the form of headaches or fatigue. It is caused by direct sunlight or strong dark and bright areas. The risk is reduced when using screening devices, such as blinds. Its perception depends on the spatial position and the vision line. *DGP* stands for Daylight Glare Probability and it is used for evaluating the glare protection in spaces addressed for reading, writing, and the use of devices and it is developed when concerning daylight in a space lit laterally. DPG should not exceed a maximum value for more than $F_{DGP,\ exceed}$=5% fraction of the space utilization time. Following the recommendations, when exceeding 0,45 glare is perceived as intolerable. When between 0,4 and 0,45 it is disturbing. When between 0,35 and 0,40 it is perceptible but tolerable, while when lower than 0,35 is imperceptible. DGP can be directly calculated using a photographic camera with HDR (High Dynamic Range), and with a visual field of 180° or higher. Alternatively, a photographic camera can be accompanied by a lux-meter.

2.4.2.4 Criticalities of EN17037:2018

The main criticality of *EN17037:2018* is the complex approach for the calculation of the metrics, elaborated by professionals for professionals, while non-experts could have many difficulties[100]. It is also not complete since it focuses on the Daylight Factor mainly, representing a static performance metric, and with the possibility of failing at reaching the minimum natural light standards with it, which is time and cost-consuming.

2.4.3 LEED Protocol, version 4.1 - Building Design and Construction

2.4.3.1 Contents and Objectives

The **Leadership in Energy and Environmental Design** (***LEED v4.1***)[101] is a globally recognized certification, which focuses on all the elements for reaching the best final building result which are all interconnected, reducing the contribution to the climate change by 35%, enhancing the human health by 20%, protecting water resources by 15%, and biodiversity by 10%, promoting the green economy with sustainable and regenerative material cycles by 10%, and giving importance to the sense of community's quality of life by 5% (*Figure 29*).

The contents of *LEED* and in particular of the updated *LEED v4.1* are:

- the integrative process;
- the location and transportation;
- the sustainable sites;
- water efficiency;
- energy and atmosphere;
- materials and resources;
- indoor environmental quality, where **daylight** is included;
- innovation;
- and regional priority.

[100] Defoe *et al.* (2020), BS EN 17037:2018 *Daylight in Buildings - A Critical Review,* DAYLIGHTING Magazine issue 24 September/ October 2020.

[101] US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction.*

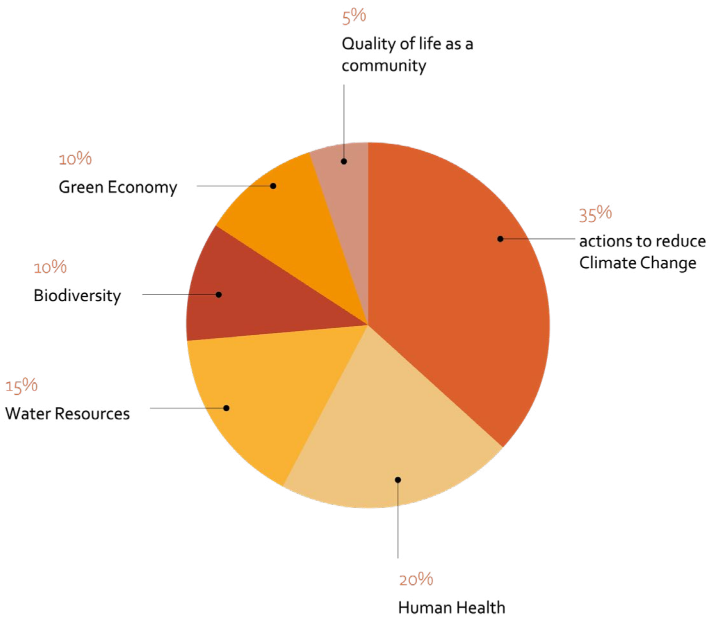

Figure 29 Contributions of LEED for the represented topics. (Source: Re-elaborated by the author from US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, https://www.usgbc.org/leed).

2.4.3.2 Introduction

LEED is the main rating system used worldwide for the design, construction, and operation phases of green buildings, which aims at always improving the building market over the years and represents sustainable achievement[102]. A total of 110 points can be granted, but at least 40 are necessary to obtain the certification. *LEED* has four levels of certifications represented by the symbols in *Figure 30*:

- Certified: 40-49 points.
- Silver: 50-59 points.
- Gold: 60-79.
- Platinum: 80+.

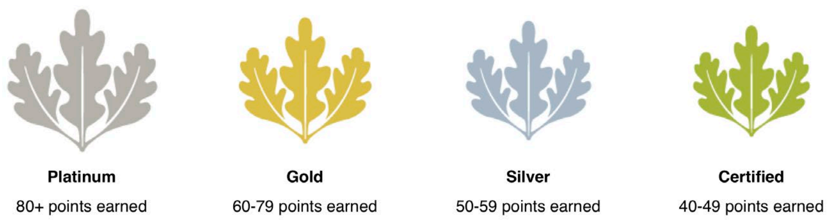

Figure 30 LEED certification levels. (Source: US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, https://www.usgbc.org/leed).

2.4.3.3 EQ Credit: Daylight

In the Indoor Environmental Quality segment, the strategies to improve the connection between occupants and the outdoors and reinforce the circadian rhythms are present, by bringing in an appropriate amount of daylight, using correct measurement and simulations to identify the

[102] US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*.

better indoor environmental quality[103]. Daylight, out of the total of 110 points, can guarantee only 1 up to 3 points. The intent of daylight is to connect the occupants of the building with the outdoors, to respect and reinforce circadian rhythms, and overall to reduce the use of electricity for electrical lighting. The requirement of this section is to provide manual or automatic shading devices for all the spaces that are regularly occupied, in order to avoid glare and discomfort. *LEED Protocol* guarantees the choice with these three options.

Option 1. Simulation: Spatial Daylight Autonomy and Annual Sunlight Exposure

The grid for the calculator to be performed needs to be less than 600 millimeters square and should occupy all the regularly occupied areas at a height of 76 millimeters above the floor[104]. Considering the nearest weather station, the data of a full meteorological year on an hourly basis is used. All permanent interior layouts need to be considered, with the exception of furniture and indoor partitions. Once the annual simulations for both the Spatial Daylight Autonomy ($sDA_{300/50\%}$) and the Annual Sunlight Exposure ($ASE_{1000,250h}$) are executed for all the regularly occupied spaces, the average $sDA_{300/50\%}$ of the total regularly occupied spaces is fpund. When $ASE_{1000,250h}$ is higher than 10% it becomes necessary to provide a solution for glare. Before the protocol review (v4.1), the 10% to be achieved was very stringent and to this day it is no longer required. The points to be assigned focus on the average $sDA_{300/50\%}$ result. 1 point is assigned when at least 40% is reached, 2 points when it is over 55%, and finally 3 points when it is higher than 75% (see *Figure 31*). The exemplary performance is achieved when all the regularly occupied space achieves at least 55% of $sDA_{300/50\%}$.

Table 1. Points for Option 1

	New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality	Healthcare
The average $sDA_{300/50\%}$ value for the regularly occupied floor area is at least **40%**	1 point	1 point
The average $sDA_{300/50\%}$ value for the regularly occupied floor area is at least **55%**	2 points	2 points
The average $sDA_{300/50\%}$ value for the regularly occupied floor area is at least **75%**	3 points	Exemplary performance

Figure 31 Table with points assigned according to the simulation's results. (Source: US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, pp. 233-234, https://www.usgbc.org/leed).

[103] In the case of Healthcare buildings, it can guarantee up to 2 points.

[104] US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, p.233.

Option 2. Simulation: Illuminance Calculations

The illuminance intensity is calculated both for the sun (direct component) and the sky (diffuse component) for a clear sky condition[105]. Considering the nearest weather station, the data of a day within 15 days of September 21st and of March 21st are used, which best are capable of having the clearest sky condition, and the average of the hourly value is used.

Any blinds or shades are excluded from the model, as well as any interior obstruction, movable furniture, or partitions. The Illuminance is being simulated at 9 a.m. and 3 p.m. on a clear-sky day and the illuminance levels results are between 300 lux and 3000 lux for each of the regularly occupied spaces. 1 point is achieved when 55% of the regularly occupied floor area is reached, 2 points in the case of at least 75%, and finally 3 points when over 90% of the space is reached (*Figure 32*).

Figure 32 Table with points assigned according to the results achieved. (Source: US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, p. 234, https://www.usgbc.org/leed).

Table 2. Points for Option 2

New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		*Healthcare*	
Percentage of regularly occupied floor area	*Points*	*Percentage of regularly occupied floor area within perimeter area*	*Points*
55%	1	55%	1
75%	2	75%	2
90%	3	90%	Exemplary performance

Option 3. Measurement

The Illuminance is being simulated in each regularly occupied space between 9 a.m. and 3 p.m. at a proper reference plane height and the results are between 300 lux and 3000 lux[106]. When the space being simulated is bigger than 14 square meters, the square grid is a maximum of 3 m; when lower is a maximum of 900 millimeters. When one point is pursued, the measurement can be taken in any regularly occupied month and at least 55% of the regularly occupied floor area needs to be reached. When two points are pursued, two measurements need to be taken in opposite months, as indicated in *Figures 33-34*, and must reach 75% for 2 points, and 90% for 3 points. For example, if the first measurement is taken in July, the second measurement is taken in November or March; when the first is taken in December, the second is taken in April or August.

[105] US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, p.234.
[106] *ibidem*, pp. 235-236.

Table 3. Points for Option 3

New Construction, Core and Schools, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		*Healthcare*	
Percentage of regularly occupied floor area	*Points*	*Percentage of regularly occupied floor area within perimeter area*	
55% at **one** time in the year	1	55% at **one** time in the year	1
75% at **two** times in the year	2	75% at **two** times in the year	2
90% at **two** times in the year	3	90% at **two** times in the year	exemplary performance

Table 4. Timing of measurements for illuminance

If first measurement is taken in ...	*take second measurement in ...*
January	May-September
February	June-October
March	June-July, November-December
April	August-December
May	September-January
June	October-February
July	November-March
August	December-April
September	December-January, May-June
October	February-June
November	March-July
December	April-August

Figure 33-34 Tables with points assigned according to the results achieved and the list of months stating when taking the measurement correctly. (Source: US Green Building Council (2020), LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction, p. 235, https://www.usgbc.org/leed).

2.4.3.4 EQ Credit: Quality Views

The quality view is the connection between building occupants and the outdoors, and it can guarantee 1 point[107]. The view to be guaranteed in a regularly occupied area needs to be clear and not obstructed by patterned glazing, frits, fibers, or tints that distort the glazing color. In this calculation, any permanent interior obstruction is included, while movable furniture and partitions can still be excluded. In 75% of the regularly occupied floor area, it must be achieved a direct line of sight towards the outdoors through glazing. In addition, at least two of the following views need to be included:

1. Multiple lines of sight in different directions (+90° apart);
2. Views including at least two of the following: flora-fauna-sky (nature), movement (activities), and objects 7.5 meters from the exterior glazing;
3. Unobstructed views;
4. Views with a view factor of 3 or higher.

The views towards an inner courtyard can be considered up to 30% of the required area.

2.4.4 The WELL Building Standard Protocol, version 2

The **WELL Building Standard** was launched by *IWBI* (International WELL Building Institute) and provides a rating system for all building typologies and settings since 2014, which aim is human health and well-being[108]. The Building Standard contains 10 concepts in relation to all types of

[107] US Green Building Council (2020), *LEED (Leadership in Energy and Environmental Design), V4.1 for Building Design and Construction*, p.237.

[108] IWBI, (2022), *WELL v2™*, https://v2.wellcertified.com/en/wellv2/overview.

buildings, included dwellings, where also light is included among others:
1. Air
2. Water
3. Nourishment
4. Light
5. Movement
6. Thermal Comfort
7. Sound
8. Materials
9. Mind
10. Community.

The points achieved are a maximum of 80 points, according to which the WELL Core Platinum is achieved (*Figure 35*).

Total points achieved	WELL Certification		WELL Core Certification	
	Minimum points per concept	Level of certification	Minimum points per concept	Level of certification
40 pts	0	WELL Bronze	0	WELL Core Bronze
50 pts	1	WELL Silver	0	WELL Core Silver
60 pts	2	WELL Gold	0	WELL Core Gold
80 pts	3	WELL Platinum	0	WELL Core Platinum

Figure 35 Table reporting WELL Certification conditions and Level of certification. (Source: IWBI, (2022), *WELL v2TM*, https://v2.wellcertified.com/en/wellv2/overview).

The concept of light contains two preconditions and 7 Optimizations. The two preconditions are the Indoor Light Provision (L01 Light Exposure) and the Visual Acuity Provision (L02 Visual Lighting Design). **Spatial Daylight Autonomy (sDA)** is introduced in WELL for point assignments and it is defined in WELL's glossary as:

"*Spatial Daylight Autonomy (sDA) is a unit that indicates the percentage of floor space, where a minimum light level (e.g., lux) can be met completely for some proportion (e.g., 0%) of regular operating hours by natural light*."[109]

The first precondition (L01 Light Exposure) requires the building under study to provide enough light exposure indoors and it is achieved when:
- from the simulations, the average $sDA_{200,40\%}$ is achieved for more than 30% of the regularly occupied spaces; or
- when the envelope glazing area is higher than 7% of the regularly occupied spaces; or
- when the unit obtains at least one point in L03 Circadian Lighting Design.

The second precondition (L02 Visual Lighting Design) focuses on the

[109] IWBI, (2022), *WELL v2TM*, https://v2.wellcertified.com/en/wellv2/glossary.

illuminances on work planes. L03 **Circadian Lighting Design** (3 points) aims at providing the inhabitants with enough light exposure for guaranteeing circadian health and the rhythm of the cycle of day and night. This is guaranteed by daylight exposure combined with electric lighting when needed, and to the outdoor views. L05 **Daylight Design Strategies** (4 points) recalls once again the combination of daylight in indoor spaces and the use of electric lighting, with a visible light transmittance over 40% and a vertical envelope glazing higher than 15% (1 point) or 25% (2 points) of the total floor area of the unit. In addition, for avoiding glare, each opening has a controllable manual shading device (1 point) or shading is automated (2 points). In L06 **Daylight Simulations**, for obtaining 1 point the average $sDA_{300/50\%}$ must be higher than 55% of the regularly occupied spaces, for 2 points the percentage to achieve is 75%.

2.5 Summary

In this Chapter have been discussed several Directives, Standards, and Protocols which included daylight indications, whether is for calculation purposes, and target results to achieve when in the design phase.
When obtaining the **Certification of Energy Performance**, following the *Energy Performance of Building Directives (EPBD)*, natural lighting is included in the list of aspects with a positive influence. The introduction of **LENI** (Lighting Energy Numerical Indicator) in the *Standard 15198-1:2018* aims at defining the total annual energy consumption for electric lighting, which can be potentially decreased through the proper use of daylight.
LEED Protocol version 4.1 - Building Design and Construction is a climate-based certification, where up to 110 points can be obtained. It provides calculations' indications and target levels for **Spatial Daylight Autonomy** and **Annual Sunlight Exposure**, as well as **Quality View**.
ITACA Protocol provides a rating system for achieving Minimum Environmental Criteria. The **average Daylight Factor** (%) calculations' indications are provided, depending on the opening geometry, and the

result is sufficient when at least 2%, and optimal when above 3%.

The Standard *EN17037:2018 - Daylight in Buildings* states the target levels of daylight depending on the **illuminance**, as well as the **Daylight Factor** calculations. The **view out** is classified depending on the layers visible and the sunlight exposure's recommendations are provided, as well as the Daylight Glare Probability (DGP) which should never exceed 5%.

Regarding Italian Decrees for residential constructions, the *Decreto del Ministero della Sanità of 5/7/1975*, states that at least **2% of average Daylight Factor** need to be always guaranteed in all regularly occupied spaces, and the window surface of each room must alway exceed **1/8 of the floor surface**.

The *Building Regulation of the City of Turin* provides the calculation's information for the average Daylight Factor in the design phase, which should be at least **3%**, as well as indications during the operation phase.

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Chapter 3
Price Analysis

3.1 Introduction

Simple and Multiple Regression Models are widely used in the real estate for estimation, descriptive, and inference purposes. These models can be applied in a multiplicity of fields. In the real estate, thanks to these analyses, the most important features buyers consider when searching for a new housing unit are found, in monetary values. With this approach, it is possible to investigate also the role of ***sustainable variables***, such as the Energy Performance of the Building and the amount of daylight in the units, in comparison to other variables which determine in greater part the listing prices.

3.2 Regression Models: the Approach

The real estate field has seen a large use of regression analysis for estimation purposes, in order to study the real estate market and to quantify monetarily each of the variables that constitute the total price[110]. The procedures for estimating the cost value can be direct (synthetic) or indirect (analytic). In the former case, the synthetic process uses monoparametric or **pluriparametric** in deterministic and probabilistic terms, better known as Simple and Multiple Regression models. The direct estimate can be chosen when an adequate number of comparable assets are available in the market segment as a comparison. In the analytic case, the *bill of quantities* is used (*Figure 36*).

[110] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 9-14.

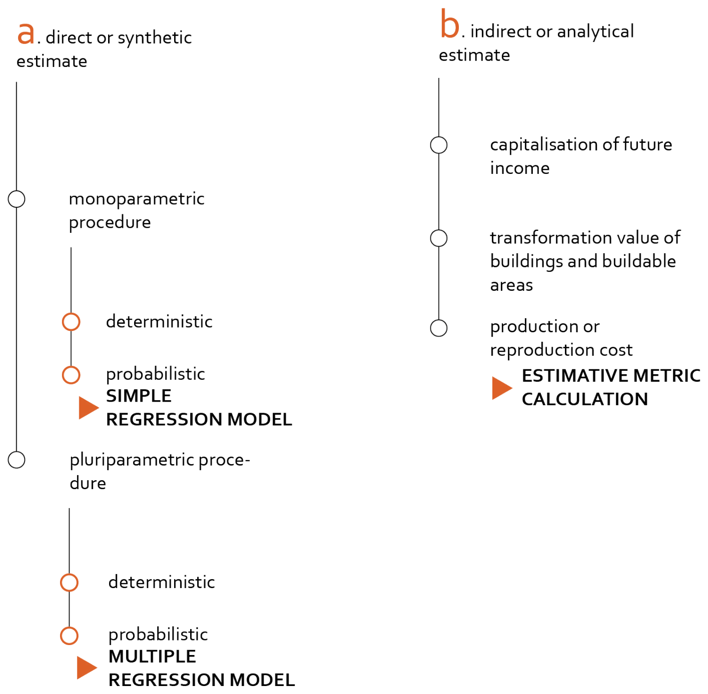

Figure 36 Synthetic and Analytic Estimate. (Source: Re-elaborated by the author from P. Morano, (2002), L'analisi di regressione per le valutazioni di ordine estimativo, Celid Torino, p. 52).

The two distinct practices can also be "mixed" obtaining the breaking down of functional elements and parameterization and the cost stratigraphy[111]. While the synthetic and the "mixed" procedures are used in the preliminary stages of a project and in the feasibility study, the analytical one is used in the final design and executive project[112].

The regression model solves in statistical terms the link between the sample and its features, through a functional relation, as stated by P. Morano:

"Data una popolazione[113] *e individuati alcuni caratteri (o fenomeni) degli elementi che la compongono, caratteri tra i quali si ipotizza l'esistenza di un legame, si vuole esplicitare detto legame mediante una relazione funzionale, a partire dalle informazioni che possono essere ottenute da un campione estratto a caso dalla popolazione."*[114]

In the regression models all variables are considered in quantitative terms, where the variable effect is represented by the **dependent variable** (or *explained* variable), and the variable cause is represented by the **independent variable(s)** (or *descriptive* variable(s)). The regression model is the research of the function which links y and x_i, where y indicates the dependent variable, and $x_1, x_2, x_3 \dots x_n$ the independent variables (21):

$$y = f(x_1, x_2, \dots, x_n) \qquad (21).$$

The random sample, after having detected the characters of k elements (of the population) will be (22):

[111] E. Fregonara (2015), Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali, FrancoAngeli, Milano, p. 35.
[112] *ibidem*, p.37.

[113] In statistics population refers to a collection of objects, not necessarily of humans.

[114] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, p. 9.

$$(y_1, x_{11}, x_{12}, \ldots, x_{1n})$$
$$(y_2, x_{21}, x_{22}, \ldots, x_{2n})$$
$$(y_3, x_{31}, x_{32}, \ldots, x_{3n})$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$(y_k, x_{k1}, x_{k2}, \ldots, x_{kn}) \qquad (22),$$

where $(y_k, x_{k1}, x_{k2}, \ldots, x_{kn})$(22) refers to the k element of the sample, y_k is the dependent variable, and $x_{k1}, x_{k2}, \ldots, x_{kn}$ are the independent variables.
When the regression model is used in the real estate, the function (22) becomes (23):

$$P = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n + e \qquad (23)$$

where P is the explicit market price, a is the constant, $b_1, b_2, \ldots, b_n$ are the implicit prices for each variable considered, and e is the stochastic and measuring error. The criterion to calculate the unknown parameters is the **Ordinary Least Squares criterion** (**OLS**) (*Figure 37*)[115].

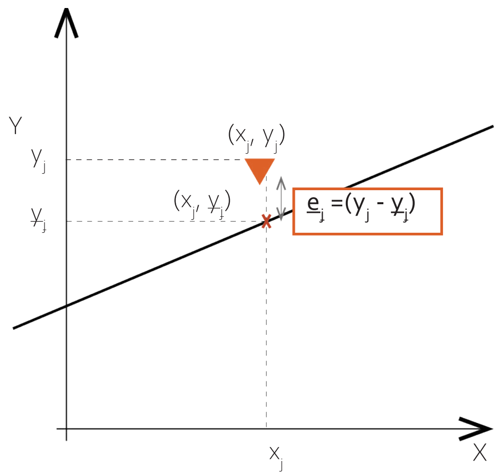

Figure 37 OLS Criterion representation. (Source: Re-elaborated by the author from P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, p. 23).

According to the Ordinary Least Squares criterion, the optimal line is the one that minimizes the squared sum of the discrepancies between the observed value and estimated value, in mathematical terms (24):

$$\sum_j (y_j - \underline{y}_j)^2 = min \qquad (24).$$

Substituting $\underline{y}_j = b_o + b_1x_j$ to $\underline{y}_j$ it is obtained (25):

$$\sum_j (y_j - bo - b_1x_j)^2 = min \qquad (25).$$

In Simple Regression, where only two parameters are unknown, the abscissa is determined by x_j, while the ordinate is found as (26):

[115] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 22-24.

$$\underline{y}_j = b_o + b_1 x_j \qquad (26).$$

The *deviation* or *residual* e_j is the difference between the two ordinates, y_j (observed point) and $\underline{y}_j$ (point estimated through the regression on the straight line), and the lower, the better the line is reliable (27):

$$\underline{e}_j = y_j - \underline{y}_j \qquad (27).$$

3.3 Multiple Regression Analysis (MRA)

The regression can be **Simple** or **Multiple** depending on how many independent variables are considered. The linear regression analysis' aim is to define the line that best approximates the hypothesized relationship between the variables[116]. In Simple Regression analysis, the dependent variable *y* is explained by only one independent variable *x* and it can be expressed by the deterministic relation (28)[117]:

$$y = f(x) \qquad (28).$$

The linear Simple Regression model is expressed as the sum of the constant parameter b_o and the product of the constant parameter b_1 and the independent variable *x*, where b_o is the intercept and b_1 the angular coefficient. Each sample observation corresponds to cartesian coordinates set on the Cartesian Plane XY (x_j, y_j). The straight line that better expresses the regression, among the infinite number of straight lines, is found as (29) (*Figure 38*):

$$y_j = b_o + b_1 x_j + e_j \qquad (29),$$

where ***e*** is the stochastic component and with $j = 1, 2, \ldots, k$.

[116] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 20-22.
[117] *ibidem*, pp,15-18.

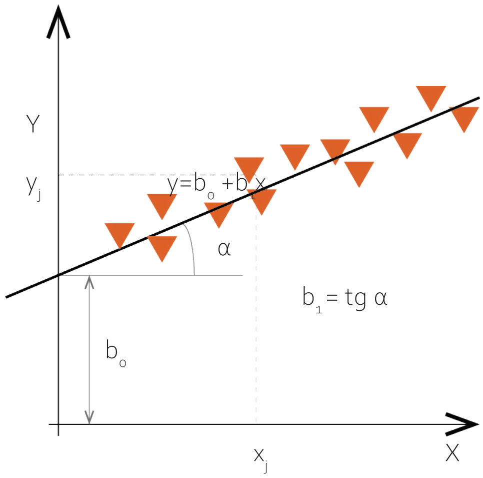

Figure 38 Linear Simple Regression model (Source: Re-elaborated by the author from P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, p. 21).

As an example, a sample of 30 housing units is detected and represented in the graph, where the surface (*m²*) and listing price (€) determine the *X* and *Y* axis. It clearly shows the *linear* price increase with the surface increase (*Figure 39*). This representation is possible because it is a simple regression model.

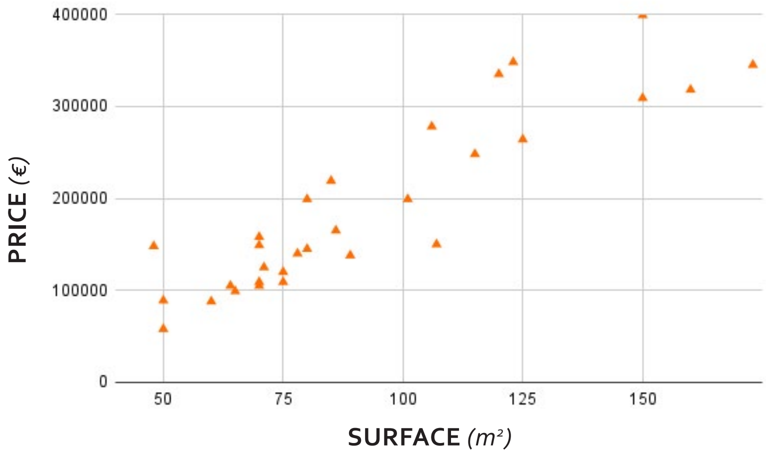

Figure 39 Representation of a sample of 30 housing units. (Source: Elaboration by the author).

The points estimated with the regression line are compared to the points of the sample observation, and once they are known it is possible to minimize their difference to better describe reality. In the example, the Simple Regression analysis defined the line that best represents the relationship between the listing price and the surface (*Figure 40*).

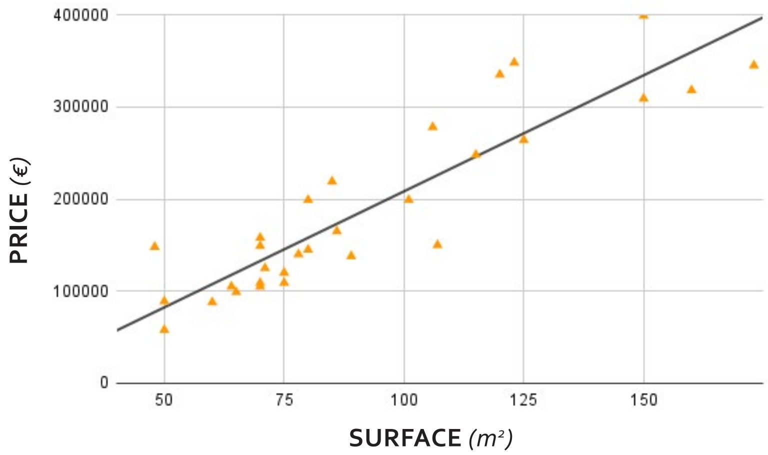

Figure 40 Linear regression analysis representation of a sample of 30 housing units. (Source: Elaboration by the author).

The reality is seldom explained by only one independent variable as the Simple Regression supports[118]. In fact, it is much more common to have multiple independent variables solved by the dependent variable, in order to understand how multiple variables influence the phenomenon under study. For example, the listing price of a housing unit is not influenced by the surface alone, but by many other factors. In the case of the Multiple Regression model, no *graphic representation* can be executed, since a *n+1* space dimensions will be needed to represent each point in a multi-plane[119]. While the Simple Regression analysis aims at identifying the line that better describes the relationship between variables, the Multiple Regression analysis aims at identifying the best (hyper)plane on the space containing the cloud of points of the random sample.

The dependent variable *y* is defined by the probabilistic model, which is to be preferred over the limitations of the *deterministic* one[120][121], and it is defined by (30):

$$y_j = f\,(x_{j1}, x_{j2}, \ldots, x_{jn}) + e_j \qquad (30)$$

with $j = 1, \ldots, k$,

where $(x_1, x_2, \ldots, x_n)$ are the independent variables and e_j is the stochastic component.

3.3.1 Multiple Regression Model (MRM) in linear and non-linear forms

The Multiple Regression Model (MRM) can be specified in a **linear form** where *f(.)* is the linear function represented as (31)[122]:

[118] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 33-35.
[119] *ibidem*, p.40.

[120] Among the limitations are: statistical inference method, unpredictable decisions in the Real Estate, reality simplification, variables selection, measuring errors, "second hand" information, no perfect mathematical relation is acknowledged.

[121] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 16-17.
[122] *ibidem*, pp. 35-36.

$$y_j = b_o + b_1 x_{j1} + b_2 x_{j2} + \ldots + b_n x_{jn} + e_j \qquad (31)$$

with $j = 1, 2, \ldots, k$.

The linear form provides an instant comprehension of the phenomenon and provides the constant **implicit marginal prices** of the characters represented with the explanatory variables (when the regression model is used for estimation purposes) and provided by the model regression parameters[123]. It implies that all the variables included enrich the explanation of the phenomenon under study, while also no link is present between the independent variables. In order for the regression model to be solved x_i variables are deterministic (their values are known), and the number of the sample's observations must be higher than the unknown parameters[124].

In many cases Multiple Regression models also approximate non-linear phenomena, using non-linear models such as the *multiplicative model* (exponential in the coefficients), the *power model* (exponential in the variables) and the ***logarithmic model*** (32):

$$y_j = b_o + b_1 \ln x_{j1} + b_2 \ln x_{j2} + \ldots + b_n \ln x_{jn} + e_j \qquad (32).$$

After calculating the logarithm of the first and second parameters, it is possible to obtain the linear form (33):

$$y' = b'_o + b'_1 x_1 + b'_2 x_2 + e' \qquad (33),$$

where x_1 and x_2 are the original model's variables, y' is the dependent variable ($y' = \log y$) and the three model coefficients b'_o, b'_1 and b'_2 are obtained as follows (34-35-36):

$$b_o = \exp b'_o \qquad (34)$$

$$b_1 = \exp b'_1 \qquad (35)$$

$$b_2 = \exp b'_2 \qquad (36).$$

3.3.2 Implicit Marginal Prices

With Multiple Regression Analysis (MRA) the statistical estimation of the implicit marginal prices (*hedonic housing prices*) of the features of the housing unit (parameters) can be found from the listing prices, and they can subsequently explain the listing price variations in the real estate market[125]. The prices of the individual features of the housing unit are called *implicit* because the value of each variable is not directly

[123] P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 43-47.
[124] *ibidem*, pp. 38-39.

[125] R. Curto, M. Simonotti, (2009), *Una stima dei prezzi impliciti in un segmento del mercato immobiliare di Torino*, Ce.S.E.T. Aestimum 22, p. 180.

expressed in the market, only the listing price is *explicit*[126]. In addition, they are *marginal* because they express the price variation for each of the variables considered[127]. The functional relation between the listing price and the implicit marginal prices is non-linear, since they are not constant[128]. Using the method of hedonic equations it is possible to decompose the price into measurable prices and quantities in regards of the individual characteristics of the dwelling, in order to predict and compare identical units[129].

The study carried out by Curto R. and Simonotti M. and published as *Una stima dei prezzi impliciti in un segmento del mercato immobiliare di Torino*[130], aims at estimating the **implicit marginal prices** (hedonic prices) in a market segment in the central area of Turin. The data sample is of 56 housing units within the same market segment and some of the variables included are listing date, location, surface, balcony surface, bathroom number, floor allocation, and view openings. The **stepwise regression analysis** is adopted and it consists in the Multiple Regression analysis, where the final result is achieved only when all variables inserted are statistically significant[131]. In the linear model, the variable coefficients represent the implicit marginal prices. From the results achieved by the study, the qualitative variables were demonstrated to be more significant than the quantitative ones, but only after the **location**.

In the experimental model carried out by Manganelli B., Tajani F. (2010) in *Modelli di stima nel mercato immobiliare - L'utilizzazione della programmazione lineare*, the determination of the listing price of a housing unit is divided into two distinct phases, where first the *marginal valuation* takes place, followed by the *global valuation*[132]. The result is then compared to the results obtained with the Multiple Regression analysis. For the ***marginal valuation*** stage, to each characteristic of the housing unit, it is assigned a monetary value, which contributes positively or negatively to the formation of the listing price of the unit. For the *global valuation*, it is summed up all the independent criteria found in the *marginal valuation* stage. The case studio analyzes 62 housing units set in a semi-central area of Naples, through 7 variables (date, surface, number of bathrooms, balcony surface, conservation state, location, metro station). The most significant variables are the ones that influence the most on the price formation. While the location and the surface are the most significant, the surface of the balconies is irrelevant, while the price varies with its presence or absence. The conservation state also does not alter the marginal price. Through the Multiple Regression analysis, the variable of the balcony surface is removed from the model, while all the other variables remain significant. The purpose of the model applied

[126] R. Scarpa, (1995), Metodo del prezzo edonico per la stima delle variazioni di benessere per beni pubblici: lo stato dell'arte e l'applicabilità in Italia, Ce.S.E.T. - Aestimum - 33, p. 96.

[127] P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 43-47.

[128] R. Scarpa, (1995), *Metodo del prezzo edonico per la stima delle variazioni di benessere per beni pubblici: lo stato dell'arte e l'applicabilità in Italia*, Ce.S.E.T. - Aestimum - 33, p. 101.

[129] S. Malpezzi, (2002), *Hedonic Pricing Models: A Selective and Applied Review, Housing Economics: Essays in Honor of Duncan Maclennan*, Madison (USA).

[130] R. Curto, M. Simonotti, (2009), *Una stima dei prezzi impliciti in un segmento del mercato immobiliare di Torino*, Ce.S.E.T. Aestimum 22, p. 179-199.

[131] *ibidem*, p. 186.

[132] B. Manganelli, F. Tajani, (2009), *Modelli di stima nel mercato immobiliare - L'utilizzazione della programmazione lineare*, siev n. 3, pp. 80-82.

is to overcome the ***curse of dimensionality*** in the Multiple Regression model, which consists in the higher number of data over the number of variables included for maintaining statistical precision[133].

3.3.3 Multiple Regression Model (MRM) Verification

The Multiple Regression Model (MRM) verifications developed in two moments[134]:

1. While in the Simple Regression model, it is identified the juxtaposition of the regression line to the observed points, in the Multiple Regression model it is verified the juxtaposition of the regression hyperplane to the points of the sample observations.
2. Secondly, the parameter's statistical significance is determined $(b_0, b_1, \ldots, b_n)$[135].

In the first step, the tests R^2 and ***SE*** are used.

On the Cartesian Plane XY, both the points of the observation and the points estimated with coordinates (x_j, y_j) are set. The ***residue analysis*** is the difference between observed and estimated values obtained with the regression analysis (*Figure 41*).

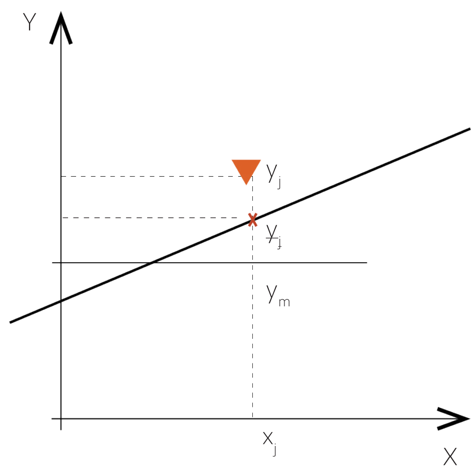

Figure 41 Residue analysis. (Source: Re-elaborated by the author from P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, p. 26).

The *determination index* R^2 is the ratio between the explained deviation (D_{EXP}) and the total deviation (D_{TOT}) and varies from 0 to 1 (37-38). The higher the residual deviation, the weaker the estimated link with the regression.

$$R^2 = \sum_j (\hat{y}_j - y_m)^2 / \sum_j (y_j - y_m)^2 \qquad (37)$$

or

$$R^2 = D_{EXP} / D_{TOT} = 1 - D_{RES} / D_{TOT} \qquad (38).$$

[133] B. Manganelli, F. Tajani, (2009), *Modelli di stima nel mercato immobiliare - L'utilizzazione della programmazione lineare*, siev n. 3, p. 87.

[134] P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 40-43.

[135] In the simple regression model the parameters are b_0 and b_1.

For the Multiple Regression analysis, the ***determination index*** R^2 is calculated as (39):

$$R^2 = (b^T X^T y - k\, y_m^2) / (y^T y - k\, y_m^2) \qquad (39).$$

R^2=0 when the regression model can't succeed in explaining the link between *x* and *y*, meaning no sample observations lie on the regression line, which instead is parallel to the abscissa (*Figure 42*).

R^2=1 when the regression line explains the link perfectly and all the points of the sample observation lie perfectly on the regression line. The closer the final result is to 1, the better the phenomenon is explained. The determination index R^2 is the percentage capable of explaining the phenomenon Y with the independent variable(s) in the regression analysis. R^2=1 means 100% is explained, and R^2=0,88 means 88% is explained (*Figure 43*).

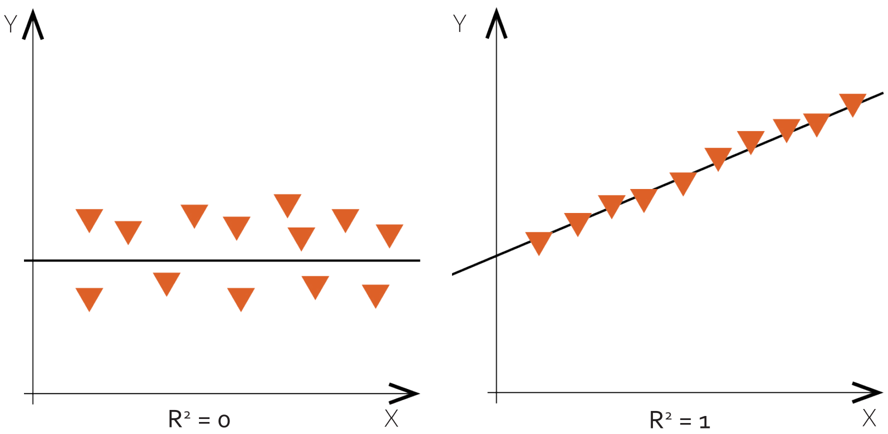

Figure 42-43 Determination Index graphical representation. (Source: Re-elaborated by the author from P. Morano, (2002) *L'analisi di regressione per le valutazioni di ordine estimativo, Celid Torino, p. 28).*

The ***corrected determination index R_c^2*** substitutes the R^2, since this last tends to overestimate the hyperplane juxtaposition to the observation sample points. The corrected determination index corrects the overestimation and it is found with (40):

$$R_c^2 = R^2 - [(n\,(1 - R^2)) / (k - n - 1)] \qquad (40).$$

The ***standard error of estimate (SE)*** is the square root of the ratio between residual deviation (discrepancy between estimated and observed data) and the number of degrees of freedom of the system (*g*[136]) (41):

$$SE = [(y^T y - b^T X^T y)/(k-(n+1))] / 2 \qquad (41).$$

[136] *g* is the difference between the *k* observations and the number of unknown parameters.

For the regression model to be accepted, the ***SE*** has to be lower than the standard deviation of the dependent variable *y*.

In the second step, the coefficients' statistical significance is verified through the ***T of Student test*** and ***F of Fischer***, after which the parameters can be accepted or not. The verification is needed since the sample aims at representing the entire population, but given the limitations in doing so, the parameters need to be tested.

The *test t of the significance of the parameters* of the model is the ratio between each of the variables (singularly) and the standard error of the parameter being tested (S_{bi}) (42):

$$t_{bi} = b_i / S_{bi} \quad \text{where } i = 1, 2, \ldots, n \qquad (42).$$

Once the values are found, the test aims at comparing the results with the statistical table of distribution **t of student**, checking the degrees of freedom of the system and the probability level of acceptance of the hypothesis, after which it is decided whether to accept the results or not.

The test **F of Fisher** aims to verify the statistical significance of all the model coefficients simultaneously.

The **variation inflation factors (*VIF*)** verifies the absence of *collinearity* between the explicative variables of the regression model, which may cause conflict with the hypothesis and the failure of the model itself. The factors are found in the element values lying on the inverse matrix main diagonal, which is inverted to the ***correlation matrix***. The variables need to abstain from any relation between each other, instead, each of the variables chosen must collaborate independently in explaining the phenomenon under study.

The correlation matrix can also identify whether some variables are statistically significant or not, where among having a coherent result with the price in the correlation matrix, they can represent a *poor quality* sample, which will lead in the exclusion on the regression model of the variables in question[137]. In addition, they can represent an imperfect relation, which can be both a potential and a limitation and, above all, make the data sample subject to the casualties of reality.

The collinearity can be present in two ways: as the *exact correlation* between two or more independent variables, where the system can't be solved since the matrix determinant $(X^T X)=0$; or as a *non-perfect correlation* between explicative variables, where the matrix determinant does not equal zero but it is very close to zero.

In addition to the previously listed verifications, it is always necessary to verify the coherence of the model, since **anomalies** could be present.

[137] B. Manganelli, F. Tajani(2009), *Modelli di stima nel mercato immobiliare - L'utilizzazione della programmazione lineare*, siev n. 3, p. 82.

As an example in an economic-estimative model, while increasing the surface the price could decrease, and the regression line could assign negative values to the prices.

3.4 Multiple Regression applied in the Real Estate Market Analysis

3.4.1 Estimative Use of the Regression Model

Regression analysis is the perfect approach for estimation (and descriptive purposes) in the real estate. As stated by Simonotti (1988):
"la possibilità di stabilire tramite il modello di regressione una correlazione tra il prezzo di mercato di un immobile e le caratteristiche intrinseche ed estrinseche che più significativamente lo influenzano, le correlazioni reciproche tra le caratteristiche e soprattutto l'effetto quantitativo esercitato da ciascuna caratteristica sul prezzo di mercato[138]",
meaning the regression model defines the incidence on listing prices of qualitative and quantitative features, it selects and finds the values of the most significant explicative variables that determine the listing price and their relation, and it is verified through a list of indexes and statistical tests[139].
The regression model follows various steps and operations from the scheme of the *giudizio di stima*[140], from the appraisal question, all the way to the final estimate result (*Figure 44*)[141].

[138] M. Simonotti, (1988), *L'analisi di regressione nelle valutazioni immobiliari*, Bollettino degli Interessi Sardi. Studi di Economia e Diritto, n. 3, p. 369.

[139] P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 77-78.

[140] *estimation judgement.*

[141] P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 49-52.

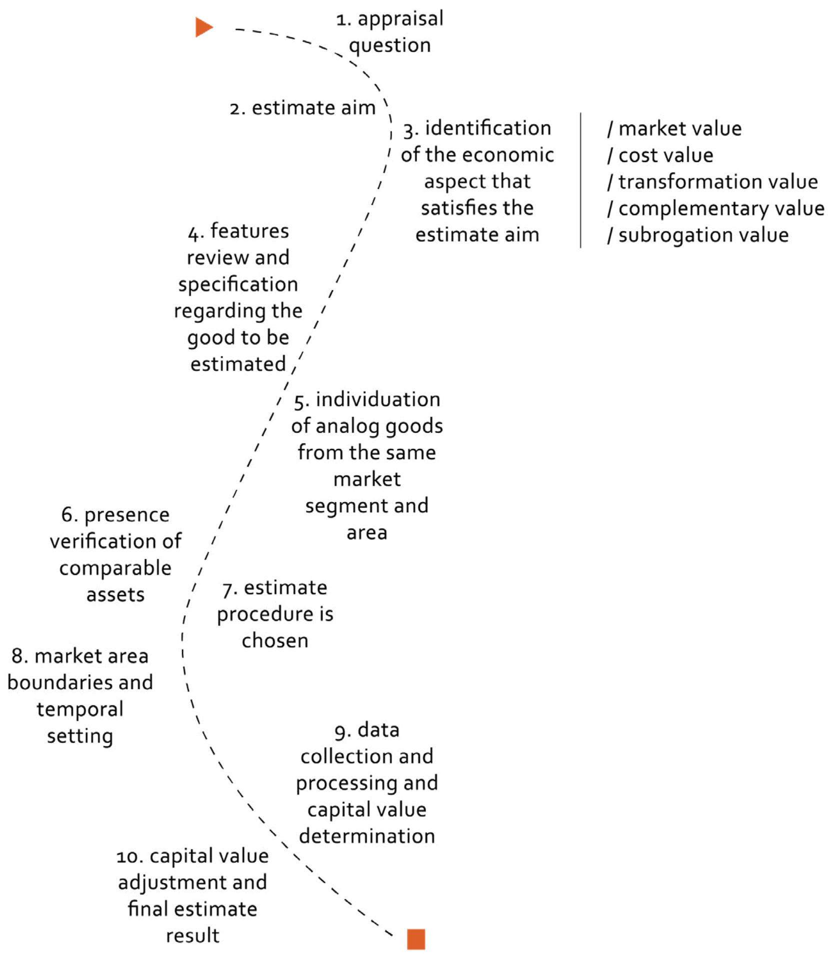

Figure 44 Regression analysis stages. (Source: Re-elaborated by the author from P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, p. 52).

Data sample is the passage where more attention needs to be taken since it will influence the coefficients' final result and must aim at representing the entire *population*. In the real estate field, listing prices and units' features are collected defining the relationship between the market price and the characteristic of each of the units, which becomes variables in the regression model.

The regression model can be classified as:

- *synthetic* or *direct* when comparable assets prices are applied[142];
- *quantitative* when using only quantitative terms;
- *uni-equational* when it is synthesized in one equation;
- *mono-parametric* or ***multi-parametric*** in the cases of, respectively, Simple and Multiple Regression;
- *linear* or *linearizable* when the parameters are linked linearly or linearizable;
- *probabilistic* when there are the components deterministic and random.

Before proceeding with the application of the regression model, it needs to be proven acceptable.

The regression analysis has a lot of potential but presents as well many limitations[143]. The most frequent ones are the presence of anomalies

[142] It is necessary to collect enough data regarding comparable asset prices in the area under study, in order to create a statistical estimation sample.

[143] P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 77-78.

in the data sample (*outliers*) and the *collinearity* between variables. In addition, it can sometimes be hard to obtain enough data within the same market segment, the qualitative variables could be subject to a personal viewpoint when transformed into quantitative values, and the elimination of the outliers could result in mistakes. Because of all these limitations, the regression analysis needs to be carried out by being aware of the phenomenon studied and acting logically in order to understand the estimated results.

3.4.2 Regression Model Construction

The regression model construction is articulated in several phases[144].

1. *The significant variables describing the phenomenon are detected.* The significant variables are the features considered by buyers and sellers which are included in the model after it has undergone proper verification.
2. *Comparable assets' data collection and representation in quantitative terms.* Data sampling is set within a specific area chosen and within a market segment, and an adequate number of comparable assets are included. Both quantitative and qualitative features need to be transformed into quantitative items.
3. *Form specification of the estimation function.* The link between all the variables included in the model is explained after it has been accepted through proper verification (determination index $\boldsymbol{R^2}$ and the corrected determination index $\boldsymbol{R_c^2}$).
4. *Estimate model verification.* A regression model can be considered verified when:

- the *determination index* R^2 is higher than 0.8;
- the *percentage error* is below 10% (ideally between 3-5%);
- the ***implicit marginal prices***[145] are compatible in sign and amount to
- the phenomenon under study and with the variable measurement modalities;
- the b/S_{bi} of *t of student test* must be higher than the *t* value[146] for each of the model coefficients;
- *F of Fisher* value must be higher than the *F* value from the statistic table in terms of degrees of freedom and trust level chosen, for all the model coefficients together;
- *VIF* below four guarantees the absence of collinearity between variables, when it is between four and five is considered "acceptable" collinearity, while if it is between five and ten it demands *ridge regression*.

5. *The model is used for estimation purposes in immutable conditions.* The explicative variables' values are known and, when substituted in the

[144] P. Morano, (2002), *L'analisi di regressione per le valutazioni di ordine estimativo*, Celid Torino, pp. 53-58.

[145] The marginal prices of the variables are estimated with the coefficients and are implicit prices because they refer to correlated and inseparable features of the unit. They express the market price variation resulting from the amounts' variations of the features' properties.

[146] From the statistical table in terms of degrees of freedom and trust level chosen.

function, it leads to the dependent variable value estimate.

The regression model in the real estate can be simplified in these four sequential stages:

1. Data sample definition and collection of housing units;
2. Units' features are transformed into explicative quantitative variables[147];
3. Results of the regression analysis;
4. Model sharpening and outliers removal[148];
5. Final regression analysis results.

In the real estate, the linear function (43):

$$y = b_o + b_1x_1 + b_2x_2 + \ldots + b_nx_n + e \qquad (43)$$

becomes (44):

$$y = \beta_o + \beta_1x_1 + \beta_2x_2 + \ldots + \beta_nx_n + e \qquad (44)$$

where y is the market price.

For each of the k observations of the sample, the system of the equation for finding the coefficients can be summed up by (45):

$$y_j = \beta_o + \beta_1x_{j1} + \beta_2x_{j2} + \ldots + \beta_nx_{jn} + e_j \qquad (45)$$

with $j = 1, 2, \ldots, k$.

3.5 Case Studies

As previously stated, data collection is the most delicate step in the regression analysis. In the real estate, while the listing prices are publicly available, the actual transaction prices are seldom provided. In Italy, there are a few entities that monitor the housing market. Among them, the **Property Market Observatory** (PMO, *Osservatorio del Mercato*

[147] Qualitative and quantitative variables are defined by levels.

[148] The *outliers* are data that cause the regression analysis to fail and for this reason, need to be removed from the sample before further steps.

Immobiliare - OMI) of the Revenue Agency (*Agenzia delle Entrate*) and the **Turin Real Estate Market Observatory** (TREMO). This last published each semester a set of data illustrating the maximum, minimum, and average prices referring to euros per square meter (*€/m²*), as well as the standard deviation and the median, and generating a comparison between the data of the last 10 years, as well as the data division of used and new or partially or totally retrofitted residential segment. The last available data refer to the year 2018[149].

3.5.1 Case Study 1

In the case study of the article *Monitoring and analysis of the real estate market in a social perspective: results from the Turin's (Italy) experience*[150], TREMO was the Turin the real estate Market Observation that aimed at constantly monitoring the Municipal Microzones. Microzones are **submarkets** and have been identified by *Presidential Decree 138/1998 "Regulation providing measures aimed at the general review of census zones, of the urban the real estate assessable values and related criteria, and of census commissions implementing article 3, paragraphs 154 and 155, of Law No. 662 dated 23 December 1966"* and their geographical borders were valid until 2018. In the city of Turin 40 territorial segments are present (*Figure 45*), which have been later substituted by OMI zones[151].

149 R. Curto, E. Fregonara, (2020), *Monitoring and analysis of the real estate market in a social perspective: results from the Turin's (Italy) experience*, SUSTAINABILITY, MDPI, Basel, 11, 3150, pp. 1-2.
150 *ibidem*, pp.1-22.
151 *ibidem*, p.3.

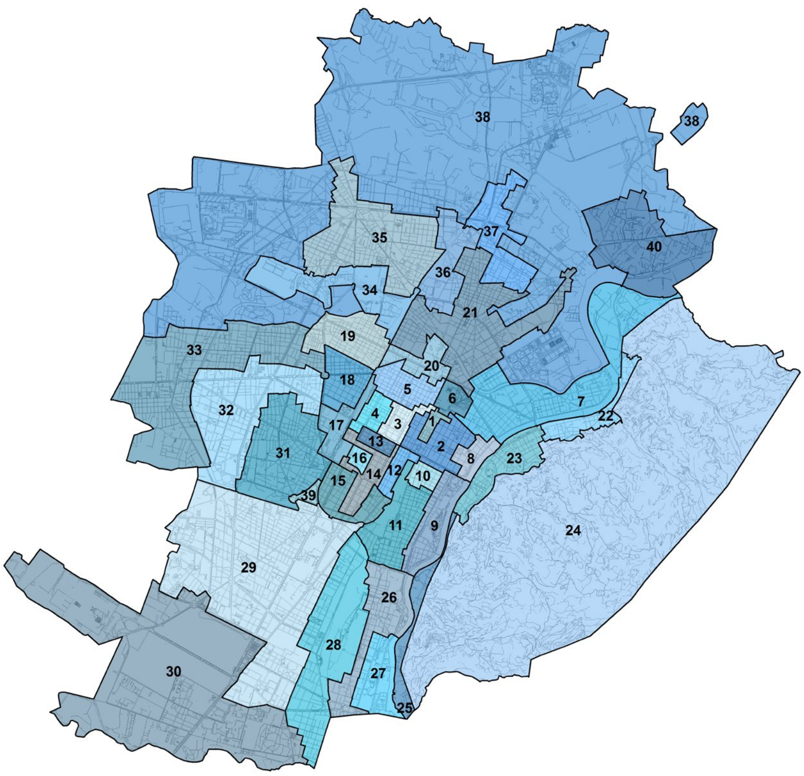

Figure 45 Turin's forty Microzones. (Source: OICT Osservatorio Immobiliare Città di Torino, *Microzone e Valori Immobiliari*, http://www.oict.polito.it/en/microzones_and_values).

The study focuses on equally representing all forty Microzones in the database, where every semester analyses are carried out. After the database creation with listing prices, transaction prices, and the amount of time spent by the housing units on the market, it undergoes a quality control process. The **Error Profile** analyzes the observed data for detecting outliers through **Box-Plots**. After proper considerations, the outliers are removed or kept in the model until the model refinement is complete[152]. When collecting data from different years, the *population* considered changes since it depends on the data availability which is not constant, but a significant amount of data must always be collected for reaching statistical relevance including all market segments. The monitoring and the analyses lead to the representation in the following images of the average prices in both used and new or partially or totally retrofitted housing units, as well as the new construction sites geographically located in each of the 40 Microzones. The location is the most noticeable variable in the images, where both in the case of used and new/retrofitted units, the central areas are always the higher in terms of prices per square meter, followed by the center surroundings and especially the hill area on the eastern part of the city (*collina* - Mircrozones 23-24), and ultimately, the periphery (*Figure 46*).

[152] R. Curto, E. Fregonara, (2020), *Monitoring and analysis of the real estate market in a social perspective: results from the Turin's (Italy) experience*, SUSTAINABILITY, MDPI, Basel, 11, 3150, p. 7.

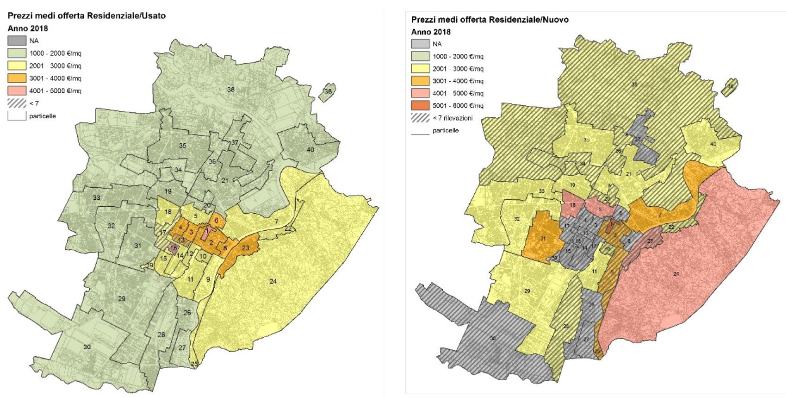

Figure 46 Average prices for used (left) and new or partially or totally retrofitted (right) housing units in Turin. (Source: R. Curto, E. Fregonara, (2020), *Monitoring and analysis of the real estate market in a social perspective: results from the Turin's (Italy) experience*, SUSTAINABILITY, MDPI, Basel, 11, 3150, p. 10, https://www.researchgate.net/publication/333635737_Monitoring_and_Analysis_of_the_Real_Estate_Market_in_a_Social_Perspective_Results_from_the_Turin's_Italy_Experience).

	Sample Agents				Sample Sellers			
Characteristic	Estimate	Standard Error	t Value	Pr(>t)	Estimate	Standard Error	t Value	Pr(>t)
(Intercept)	11.972	0.099	121.083	$<2 \times 10^{-16}$ ***	11.424	0.427	26.752	$<2 \times 10^{-16}$ ***
Microzone 1	Omitted				Omitted			
Microzone 2	−0.296	0.102	−2.896	0.004 **				
Microzone 3	−0.103	0.108	−0.951	0.342	0.639	0.443	1.445	0.161
Microzone 4	−0.191	0.114	−1.680	0.093 ****				
Microzone 5	−0.210	0.106	−1.978	0.048 *	0.101	0.504	0.200	0.843
Microzone 6	−0.098	0.142	−0.690	0.490				
Microzone 7	−0.424	0.108	−3.939	0.000 ***	0.088	0.433	0.203	0.840
Microzone 8	−0.250	0.112	−2.242	0.025 *				
Microzone 9	−0.342	0.111	−3.077	0.002 **	0.142	0.480	0.295	0.770
Microzone 10	−0.545	0.112	−4.850	0.000 ***	−0.194	0.486	−0.399	0.693
Microzone 11	−0.503	0.105	−4.772	0.000 ***	0.164	0.443	0.371	0.714
Microzone 12	−0.512	0.115	−4.439	0.000 ***	0.458	0.438	1.046	0.305
Microzone 13	−0.234	0.158	−1.482	0.139				
Microzone 14	−0.236	0.113	−2.099	0.036 *				
Microzone 15	−0.354	0.109	−3.258	0.001 **	0.362	0.449	0.807	0.427
Microzone 16	0.086	0.133	0.647	0.518				
Microzone 17	−0.327	0.123	−2.657	0.008 **				
Microzone 18	−0.412	0.109	−3.778	0.000 ***	0.169	0.527	0.321	0.751
Microzone 19	−0.776	0.103	−7.537	0.000 ***	−0.279	0.444	−0.627	0.536
Microzone 20	−0.735	0.112	−6.571	0.000 ***	−0.442	0.441	−1.002	0.326
Microzone 21	−1.034	0.102	−10.141	$<2 \times 10^{-16}$ ***	0.017	0.475	0.035	0.972
Microzone 22	−0.393	0.119	−3.310	0.001 ***	−0.166	0.438	−0.379	0.708
Microzone 23	−0.108	0.113	−0.961	0.337				
Microzone 24	−0.481	0.099	−4.854	0.000 ***	0.839	0.394	2.129	0.043 *
Microzone 25	−0.546	0.121	−4.500	0.000 ***	0.100	0.484	0.206	0.838
Microzone 26	−0.669	0.107	−6.252	0.000 ***				
Microzone 27	−0.651	0.118	−5.531	0.000 ***	−0.154	0.496	−0.311	0.758
Microzone 28	−0.750	0.110	−6.830	0.000 ***	−0.044	0.443	−0.100	0.921
Microzone 29	−0.603	0.099	−6.084	0.000 ***	−0.015	0.422	−0.036	0.971
Microzone 30	−0.742	0.113	−6.561	0.000 ***	0.333	0.486	0.685	0.499
Microzone 31	−0.657	0.109	−6.028	0.000 ***	−0.014	0.418	−0.034	0.973
Microzone 32	−0.488	0.104	−4.674	0.000 ***	0.162	0.464	0.349	0.730
Microzone 33	−0.680	0.103	−6.624	0.000 ***	−0.174	0.478	−0.365	0.718
Microzone 34	−0.669	0.117	−5.696	0.000 ***				
Microzone 35	−0.895	0.103	−8.725	$<2 \times 10^{-16}$ ***	−0.388	0.423	−0.917	0.368
Microzone 36	−1.002	0.115	−8.720	$<2 \times 10^{-16}$ ***				
Microzone 37	−0.804	0.109	−7.409	0.000 ***				
Microzone 38	−0.884	0.111	−7.936	0.000 ***	−0.253	0.433	−0.583	0.565
Microzone 39	−0.287	0.126	−2.273	0.023 *				
Microzone 40	−0.840	0.113	−7.411	0.000 ***				
Building quality_1	−0.101	0.059	−1.733	0.083 ****	−0.340	0.204	−1.667	0.108
Building quality_2	Omitted				Omitted			
Building quality_3	0.199	0.024	8.227	0.000 **	−0.228	0.118	−1.922	0.066 ****
Building quality_4	0.452	0.062	7.240	0.000 ***	0.132	0.343	0.386	0.703
Building quality_5	0.330	0.034	9.684	$<2 \times 10^{-16}$ ***	−0.025	0.182	−0.140	0.890
Size (sqm)	0.008	0.000	40.710	$<2 \times 10^{-16}$ ***	0.010	0.002	6.202	0.000 ***
Terrance_1	0.061	0.023	2.683	0.007 **	−0.410	0.170	−2.416	0.023 *
Garage_1	0.086	0.030	2.907	0.004 **	−0.056	0.150	−0.373	0.712
Year 2011	Omitted				Omitted			
Year 2012	−0.101	0.018	−5.686	0.000 ***	0.055	0.105	0.521	0.607

Notes: Sample agents: Significance codes: *** $0 < Pr(>|t|) < 0.001$; ** $0.001 < Pr(>|t|) < 0.01$; * $0.01 < Pr(>|t|) < 0.05$; **** $0.05 < Pr(>|t|) < 0.1$; † $0.1 < Pr(>|t|) < 1$; residual standard error: 0.2892 on 1070 df; multiple R-squared: 0.8637; adjusted R-squared: 0.8577; F-statistic: 144.2 on 47 and 1070 DF, p-value: $< 2.2 \times 10^{-16}$; sample sellers: Significance codes: *** $0 < Pr(> |t|) < 0.001$; ** $0.001 < Pr(>|t|) < 0.01$; * $0.01 < Pr(>|t|) < 0.05$; **** $0.05 < Pr(>|t|) < 0.1$; † $0.1 < Pr(>|t|) < 1$; residual standard error: 0.2439 on 26 df; multiple R-squared: 0.9265; adjusted R-squared: 0.8359; F-statistic: 10.24 on 32 and 26 df, p-value: 2.393×10^{-8}.

Figure 47 Regression analysis example considering all Turin's 40 Microzones. (Source: R. Curto, E. Fregonara, (2020), Monitoring and analysis of the real *estate market in a social perspective: results from the Turin's (Italy) experience*, SUSTAINABILITY, MDPI, Basel, 11, 3150, p. 13, https://www.researchgate.net/publication/333635737_Monitoring_and_Analysis_of_the_Real_Estate_Market_in_a_Social_Perspective_Results_from_the_Turin's_Italy_Experience.

In the table above (*Figure 47*) the regression analysis carried out focuses on the listing prices in all 40 Microzones of Turin (sample agents on the left - sample sellers on the right). Among the Microzones, variables such building's quality, surface, terrace, and garage are included. Price spatial analysis models are used to find the repercussion location has on sub-markets housing prices, while liquidity, which is the time the unit remains unsold, is not affected by it.

3.5.2 Case Study 2

The ***Energy Performance Certificate*** (EPC) is a mandatory data that needs to be provided in the real estate advertisements since 2012, and its significance has been questioned through the Hedonic regression analysis in a sample of 879 units. The data is collected in regard to the years 2011-2014 in Turin. When juxtaposing the building construction year and the EPC level, it is noticeable that the units relatively old have lower EPC levels (between C and G)[153].

The problem the city of Turin, analogous to many other Italian cases, is the fact that a great percentage of the building stock, 49%, consists of

[153] E. Fregonara, D. Rolando, P. Semeraro, (2017), *Energy performance certificates in the Turin real estate market*, Journal of European Real Estate, VOl. 10 No. 2, 2017, pp.149-169.

units realized between 1946 and 1970, present in the most vulnerable part of the city[154]. This 49% are energy inefficient and need to undergo renovations.

Together with the EPC levels (from A to G), the other variables considered were the sale year, the building and apartment condition, the apartment size, the construction year, the quality level, and the 40 Microzone (location)[155]. Through the hedonic regression model, the EPC levels are confirmed to not be significant variables, while the most significant results are: the sale year, the apartment conditions, the construction year, and the quality of the building. This is rather not to be expected in the Italian market, but may be due to the awareness-less of the potential energy savings guaranteed with a higher initial investment, with lower maintenance costs, energy savings over the building's service life, and the reduction of energy consumption.

3.5.3 Case Study 3

P. Semeraro and E. Fregonara, in *The impact of house characteristics on the bargaining outcome*[156], analyzed the differences between listing price and selling price through hedonic regression models with a sample of 534 data in relation to the years 2007-2010. The actual selling price is a data hard to put hands on due to the lack of transparency in the Italian real estate market. The 40 Microzones in Turin were once again used for representing geographical submarkets (*geographical segmentation*), in order to determine the location and its impact on listing prices. From the TREMO's database, an example of regression analysis is carried out. The variables collected include: the listing price, the selling price, the time spent by the units on the market, the size, the number of rooms, bathrooms, balconies and terraces, the presence of the elevator and of the caretaker, the number of floor, and the unit condition, and the Microzone. The Multiple Regression analysis has been carried out twice, with listing and selling prices as dependent variables. The marginal prices present, for each variable, a positive or negative sign, and the "*", "**", "***" present the significance level of the variable. The coefficient of determination R^2 is 0.79 (adjusted R_c^2 0.78) for the listing price, 0,81 (adjusted R_c^2 0.79) for the selling price.

The results showed the variables influencing the most the price, which are factors not always considered during the negotiation. In the first model the balconies, the number of rooms and a low building quality didn't result significant, instead the location, a high building and unit quality, and the presence of the elevator were the most significant

[154] A. Barreca, C. Curto, D. Rolando, (2018), *Housing Vulnerability and Property Prices: Spatial Analyses in the Turin Real Estate Market*, Sustainability 2018, 10(9), 3068, Torino.

[155] E. Fregonara, D. Rolando, P. Semeraro, (2017), *Energy performance certificates in the Turin real estate market*, Journal of European Real Estate, VOl. 10 No. 2, 2017, p.163.

[156] P. Semeraro, E. Fregonara, (2013), The impact of house characteristics on the bargaining outcome, J. Eur. the real estate Res. 2013, 6, pp. 262–278.

variables. Very similar is the result in the second model, where once again the Microzone's variables (the location) are the most significant with a high building quality and unit condition, and the presence of the elevator.

3.5.4 Case Study 4

The aim of the research *Location and property values: a study for the territorial sub-segmentation of Turin's Microzones*[157] by Barreca A., Curto R., and Rolando D. has been to delineate the sub-segmentation in regards to historical built environments and their stratifications within each microzone of Turin (40), without altering their perimeter but instead splitting it into 93 portions (*Figure 48*).

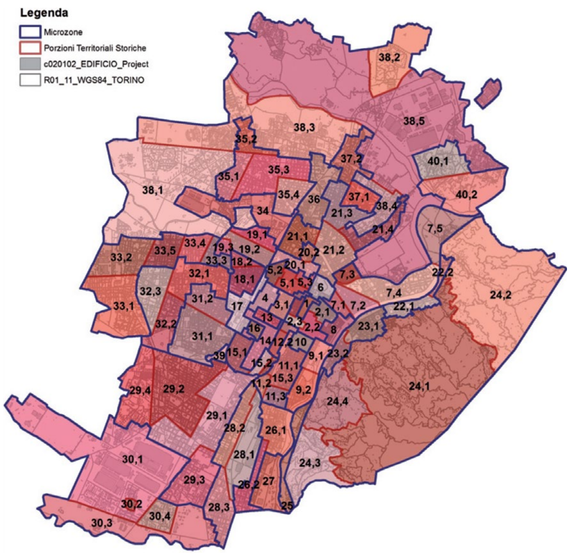

Figure 48 40 Microzones and 93 historical territorial portions (PTS). (Source: A. Barreca, R. Curto, D. Rolando, (2017), *Location and property values: a study for the territorial sub-segmentation of Turin's Microzones*, Territorio Italia, Vol.1, n. 1/17, Agenzia delle Entrate, Italy, p. 55, https://doi.org/10.14609/Ti_1_17_2i).

In the study has been used a traditional hedonic model to define the listing prices of the housing units in the 93 historical territorial portions, identifying the explicative variables referring to location and unit features information, detected from the real estate advertisements.

The sample consisted of 1758 data of listing prices of housing units collected between the years 2013 and 2016. No outliers were deleted from the sample, but it has been refined deleting units at the ground floors and top floors, as well as isolated units which do not present higher floors. In this way, "floor allocation", a variable that is usually hardly defined in hedonic models, will not influence the data sample.

The variables considered for each unit and respective building can be categorized into:

- <u>Location</u> (40 Microzone and 93 PTS);
- <u>Category</u> (year of the advertisement, construction year, state of

[157] A. Barreca, R. Curto, D. Rolando, (2017), *Location and property values: a study for the territorial sub-segmentation of Turin's Microzones*, Territorio Italia, Vol.1, n. 1/17, Agenzia delle Entrate, Italy, pp. 49-71.

conservation, building category);

- Floor allocation and elevator presence.

The average price of the sample is **2363 €/m²** with a standard deviation of 1051 €/m². The higher listing prices haven't been treated as outliers because they represent the units located in the most prestigious area of the city, the city center, and the hill ("*collina*" is the easternmost area of the city). In some examples of PTS analyzed, the sample is dishomogeneous within the same microzones, due to physical barriers such as rivers or rails (*Figure 49*).

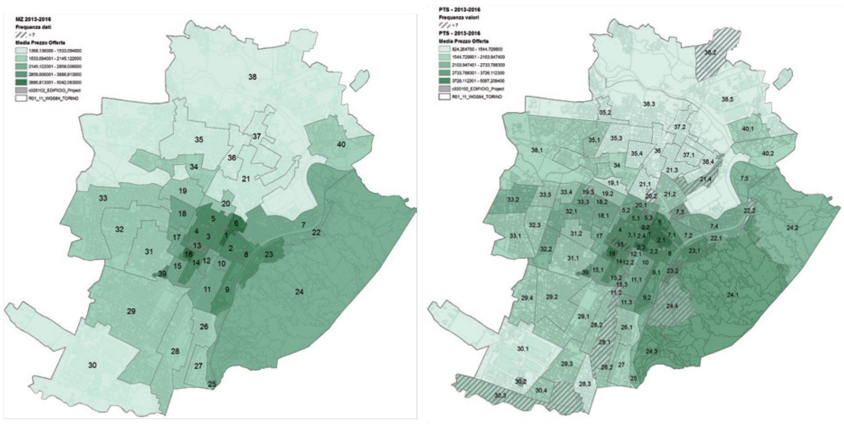

Figure 49 40 Microzones and 93 historical territorial portions (PTS) listing prices. (Source: A. Barreca, R. Curto, D. Rolando, (2017), *Location and property values: a study for the territorial sub-segmentation of Turin's Microzones*, Territorio Italia, Vol.1, n. 1/17, Agenzia delle Entrate, Italy, p. 60, https://doi.org/10.14609/Ti_1_17_2i).

The variables considered for the analysis have been selected after testing different combinations and finding the most suitable ones, always avoiding **multicollinearity**. The variables excluded by the model are: the number of rooms, the number of views, the presence and number of balconies and terraces, the presence of the reception desk, and the level of EPBD (Energy Performance of the Building / in it. *APE, Attestato di Prestazione Energetica*). The study carries out two distinct analyses: firstly having as location variable the 40 Microzones, and secondly considering the 93 PTS (historical territorial portions).

I. In the first analysis, the 40 Microzones are the location variable under study. The analysis uses as a dependent variable the logarithm of the listing price, resulting in an Adjusted R_c^2 to **0,8**. The p-value obtained is close to zero, meaning the relationship is statistically significative (≤0,05) (*Figure 50*).

As a result, almost all Microzones resulted significative, and the ones with the higher positive value are the most prestigious.

The year of the advertisement resulted significative and the decreasing value from 2013 to 2016 depicts the economic-financial crisis. The state of conservation is the variable that most influences the listing price. The most prestigious and new constructed buildings are the ones influencing mostly the listing price (*Figure 51*).

		PREZZO UNITARIO DI OFFERTA (log) (Variabile dipendente)			
Variabile	LIVELLI	ESTIMATE	St. Error	Pr(>|t|)	
(Intercept)		7,56	0,04	< 2e-16	***
Microzona	1	0,67	0,05	< 2e-16	***
	2	0,40	0,05	< 2e-16	***
	3	0,35	0,05	0,00	***
	4	0,30	0,05	0,00	***
	5	0,25	0,05	0,00	***
	6	0,46	0,05	< 2e-16	***
	7	0,03	0,05	0,49	
	8	0,39	0,05	0,00	***
	9	0,28	0,05	0,00	***
	10	0,09	0,05	0,09	.
	11	Omesso			
	12	0,10	0,05	0,06	.
	14	0,17	0,20	0,41	
	15	0,26	0,05	0,00	***
	16	0,11	0,05	0,03	*
	17	0,56	0,09	0,00	***
	18	0,00	0,12	0,98	
	19	0,16	0,05	0,00	**
	20	-0,13	0,05	0,01	**
	21	-0,48	0,04	< 2e-16	***
	22	0,14	0,06	0,01	**
	23	0,42	0,05	0,00	***
	24	0,21	0,06	0,00	***
	25	0,04	0,06	0,58	
	26	-0,21	0,05	0,00	***
	27	-0,13	0,05	0,01	*
	28	-0,21	0,05	0,00	***
	29	-0,17	0,04	0,00	***
	30	-0,29	0,05	0,00	***
	31	-0,17	0,05	0,00	***
	32	-0,12	0,04	0,01	**
	33	-0,16	0,04	0,00	***
	34	-0,31	0,07	0,00	***
	35	-0,45	0,04	< 2e-16	***
	36	-0,46	0,05	< 2e-16	***
	37	-0,48	0,05	< 2e-16	***
	38	-0,41	0,05	< 2e-16	***
	39	0,06	0,07	0,40	
	40	-0,27	0,07	0,00	***

Figure 50 40 Microzones hedonic model result. (Source: A. Barreca, R. Curto, D. Rolando, (2017), *Location and property values: a study for the territorial sub-segmentation of Turin's Microzones*, Territorio Italia, Vol.1, n. 1/17, Agenzia delle Entrate, Italy, p. 63, https://doi.org/10.14609/Ti_1_17_2i).

		PREZZO UNITARIO DI OFFERTA (Variabile dipendente)			
Variabile	LIVELLI	ESTIMATE	St. Error	Pr(>|t|)	
Data di offerta dell'unità immobiliare sul mercato (anno)	2013	Omesso			
	2014	-0,09	0,02	0,00	***
	2015	-0,17	0,02	< 2e-16	***
	2016	-0,19	0,02	< 2e-16	***
Stato di conservazione dell'unità immobiliare	Ristrutturato	0,24	0,02	< 2e-16	***
	Medio	0,16	0,02	0,00	***
	Parzialmente da ristrutturare	0,06	0,02	0,00	**
	Totalmente da ristrutturare	Omesso			
Piano di allocazione dell'unità immobiliare in presenza/assenza dell'ascensore	Piano 1 - no ascensore	0,01	0,04	0,72	
	Piano 1 - sì ascensore	Omesso			
	Piano 2 - no ascensore	-0,07	0,04	0,08	.
	Piano 2 - sì ascensore	0,08	0,02	0,00	***
	Piano 3 - no ascensore	-0,01	0,04	0,73	
	Piano 3 - sì ascensore	0,06	0,02	0,00	**
	Piano 4 - no ascensore	-0,19	0,06	0,00	**
	Piano 4 - sì ascensore	0,06	0,02	0,00	**
	Piano 5 - no ascensore	-0,33	0,08	0,00	***
	Piano 5 - sì ascensore	0,04	0,02	0,08	.
	Piano 6 - no ascensore	-0,18	0,20	0,36	
	Piano 6 - sì ascensore	0,06	0,03	0,06	.
	Piano 7 - sì ascensore	0,14	0,04	0,00	***
	Piano 8 - sì ascensore	0,08	0,05	0,17	
	Piano 9 - sì ascensore	0,22	0,06	0,00	***
Categoria dell'edificio	Pregio	0,28	0,03	< 2e-16	***
	Signorile	0,20	0,02	< 2e-16	***
	Medio	0,08	0,02	0,00	***
	Economico	Omesso			
	Popolare	-0,16	0,04	0,00	***
Periodo di costruzione dell'edificio	< 1946	-0,04	0,02	0,01	**
	1946-1980	Omesso			
	>1980	0,09	0,03	0,00	**
	Adjusted R^2	**0,80**			
	p-value	**<2,2e-16**			

Livello di significatività: 0 '***' 0,001 '**' 0,01 '*' 0,05 '.' 0,1 ' ' 1

Tabella 6 Risultati derivanti dalla prima applicazione del modello edonico (variabile localizzativa: Microzona).
Le Microzone che presentano sotto-campioni statisticamente non significativi
a causa della scarsa numerosità sono state omesse dalla presente tabella
Fonte: Elaborazione degli Autori

Figure 51 Other variables considered in the hedonic model and results. (Source: A. Barreca, R. Curto, D. Rolando, (2017), *Location and property values: a study for the territorial sub-segmentation of Turin's Microzones*, Territorio Italia, Vol.1, n. 1/17, Agenzia delle Entrate, Italy, p. 64, https://doi.org/10.14609/Ti_1_17_2i).

II. In the second analysis, the 93 PTS substitutes the 40 Microzones. As a result, the adjusted R_c^2 is 0,81. The p-value obtained is also close to zero, confirming once again the statistical significance of the relationship between dependent and independent variables. As a result, also the 93 PTS resulted significative, highlighting the good result of the model used, which confirms the variation of the location to be essential in the price formation.
Through this analysis, the location is confirmed to be highly influencing the price formation, but an additional matter to be taken into account is the surroundings, such as the view out from the windows of the units under study, to comprehend the high or low value.

3.6 Summary

Simple and Multiple Regression models are optimal tools to be adopted in the real estate, for both estimative and descriptive purposes. When collecting a significative data sample, and after having removed the outliers if present, the model is refined until no variables with collinearity are present. Finally, in order to accept the model's result, the adjusted R_c^2 needs to be higher than 0,5 and all variables need to be significant (shown graphically with the symbol *, **, ***). In the examples provided, the variables showing the most significance are the location, when data are spread in a wide area and inhomogeneous, the presence of elevators in buildings with many floor levels, the state of conservation, the category, and the construction year.

Bibliography Chapter 3

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PART II - Case-study: Simulations and Multiple Regression Analysis for the construction of a predictive and explicative model

Chapter 4
Methodology of the Research

4.1 Introduction

The research has been developed in order to investigate the value of daylight in the housing market in Turin. Many times when buyers search for a new unit where to move in, one of the characteristics is a bright space with loads of natural light. But how is the best way to quantify daylight?

The research has followed a rich workflow, from the state of the art research to data collection, from the daylight simulations to Multiple Regression Analysis, with the objective to determine the implicit marginal prices of the new *green variables* that have been introduced.

4.2 Aim and Objectives

This Master's Thesis aims at defining the role of **daylight** in the real estate, starting from its quantification and multiple definitions, with the final objective of identifying the value daylight has in the composition of the listing price. The daylight metrics are multiple and can't be summed up only by a single value. The legislation is different in each country and the Italian legislation seems still to be lacking.

Daylight can be considered a ***green variable*** because its proper design and efficiency can lead to a decrease in energy loads due to artificial lighting and cooling.

This study aims at demonstrating how important daylighting is and how proper consideration must be given, ensuring a higher lifestyle for

the inhabitants and demonstrating that it has a monetary value not to disregard.
The data sampling wants to be a considerate example for quantifying in monetary terms natural light, using both qualitative and quantitative data. Thanks to the Multiple Regression Analysis this is possible for estimation and descriptive purposes.

The final questions of this study are:

"How can daylight be properly quantified and which are the limitations?"

"Can daylight be considered as a value in the real estate market and not only as a descriptive characteristic?"

4.3 The Workflow

The workflow of the research can be described as follows (*Figure 52*):

1. The theme is the daylight in the housing market. The research aims at investigating the monetary values that natural light can have, through Multiple Regression analysis, defining if the **green variables** (such as Daylight Factor, the spatial Daylight Autonomy, the Useful Daylight Illuminance, the Annual Sunlight Exposure) are being appreciated in the real estate.

2. The research on the state of art has started to acquire the basic theoretical aspects in both fields (building physics and economic valuation), particularly, the importance of daylighting for the well-being of humans, the understanding of daylighting indicators and legislations, as well as the use of Multiple Regression.

3. The location is chosen and the data of 100 units have been collected. A limit of 100 has been decided as significant for the research. More data

would have been ideal and capable of explaining the market even better, but 100 cases were considered the best trade-off between richness of the data-set and simulation time, since each unit considered would have to be modeled and simulated individually. All qualitative data has been transformed into quantitative and all categories have been included in the Excel Datasheet, which is fully reported in *Annex A - Extensive Dataset and Simulation Results*.

4. From the data collection, a 3D model of the 100 case studies selected has been created using the floor plan images provided by the advertisements and the city plan provided by Turin's Municipality. The 100 3D models were used to run daylighting simulations, using the validated ClimateStudio, provided by Solemma. All the results have been once again categorized in quantitative terms and added to the Excel Datasheet.

5. The Excel Datasheet with all the information has been elaborated and simplified, so as to include data needed for the Multiple Regression analysis only.

6. The correlation analysis has been used to avoid collinearity between the variables; in other words, the data linked to each other have been excluded as they cannot be co-present in the same regression model.

7. If present, outliers have been removed from the data sample since they present data outside of the market segment considered and this could significantly alter the results.

8. The Multiple Regression analysis has been carried out, choosing one dependent variable and the explicative variables until the final models have been found. The models have been refined until all the variables in each model were found to be significant and not correlated. Verifications need to take place.

9. A final interpretation of the results and conclusions have been eventually drawn.

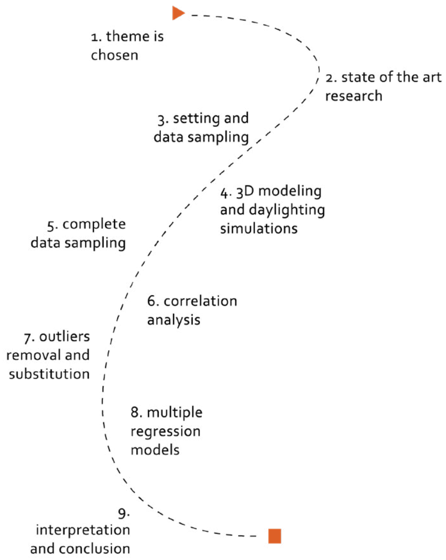

Figure 52 Workflow of the study. (Source: Elaboration by the author).

4.4 The Data Sampling

4.4.1 Data Typologies

Data sampling is of different typologies. **Primary data**[158] is collected from the website www.immobiliare.it, where it is possible to find listing prices of apartments.

Descriptive data are gathered thanks to the information provided by the advertisement photos; **experimental data**, instead, are obtained by manipulating the variables, such as in the case of the simulation results.

4.4.2 Methodological Approach and Methods

The experimental study uses **quantitative methodological approaches**, which aim to produce generalizable knowledge to be replicated by others in the future. In order to be replicated, the quantitative research methods need to be carefully described.

The **quantitative research methods** can be found in Chapter 5, where all the variables are carefully explained. The data sample consists of **100 case studies** published online in the last trimester of 2022. In the real

158 Data collected by the author.

estate market, it is important not to consider wide time ranges since the market changes every semester, and a data sample of one whole year in the case of this study would not be optimal. It is worth mentioning that it is unknown whether the data has been published previously and only reposted later on, meaning there is no data referring to how long a house has been on the market. As well as it is given the listing price of the units, but not the actual selling price, which could be both higher or lower.

The 100 apartment units have been selected when all the information required was present, such as photos of the apartment, proper description to allow categorization of all the variables to be done, energy performance of building indicators, and the floor plan of the unit. Particularly, it wouldn't be possible to develop the building simulations for daylighting in the absence of the floor plan.

Only on another stage, outliers have been eliminated and substituted: outliers were mostly linked to apartments in very good condition hence with a disproportionately higher price compared to the other units that composed the dataset, as they would be a *bias* in the model.

4.5 The Software

For the development of the research these following packages have been used.

Starting from the collection of resources and the drafting of the research **Microsoft Word**[159] has been used.

The data collection has been developed in **Microsoft Excel**[160], for the easy creation of graphs for describing the results.

The simulations have seen the initial use of **Autodesk Revit**[161] for the basic 3D modeling, next imported in **Rhino 7**[162] and prepared for the simulations with the plug-in by **Solemma, ClimateStudio**[163].

The Excel Spreadsheet has then been imported into **Gretl** (*Econometric software for the GNU generation*)[164], where the outliers, if present, have been found and substituted with new data, followed by the Multiple Regression models. Finally, the layout has been improved in **Adobe InDesign**[165] and schemes have been created using **Adobe Illustrator**[166].

159 Microsoft Corporation, *Microsoft Word*, available at https://products.office.com/word.

160 Microsoft Corporation, *Microsoft Excel*, available at https://office.microsoft.com/excel.

161 Autodesk INC., *Revit*, available at https://www.autodesk.eu/products/revit.

162 McNeel R., *et al.*, *Rhinoceros 3D*, Version 7, Robert McNeel & Associates, Seattle, WA.

163 Solemma LLC., *Climate Studio*, USA, available at https://www.solemma.com/cs-trial.

164 Baiocchi G., Distaso W., (2003), *GRETL: Econometric software for the GNU generation*, JSTOR.

165 Adobe Inc., *Adobe InDesign*, available from https://adobe.com/products/indesign.

166 Adobe Inc., *Adobe Illustrator*, available from https://adobe.com/products/illustrator.

4.6 Difficulties and Limitations

During the data collection, the units to be included have been chosen by the author according to the completeness of the information provided, thus excluding some units over others. Furthermore, 100 units was estimated to be a solid data sample, even though for having a complete database, it would have been necessary to have a sample much higher than this.

The floor plans provided by the advertisement were very often **lacking measurements**, for this reason, the floor plan scaling when modeling in 3D has been approximated and the final square meters of the units were never coinciding with the measurements provided by the advertisement, leading in some incongruences and daylighting simulations results not always complying to regulations. Also, the floor height and window and door sizes have always been approximated according to the photos, since no information about them is provided, limiting the final results to an approximation of reality.

Through the use of the software Gretl, it has been possible to define the **outliers** and only through a **one-by-one** verification, it has been considered the acceptance or substitution of the unit. The outliers are, in fact, data that stands out from the rest of the dataset and should be removed from the sample because of bias. In some cases, they can be kept, but in the example of a housing unit with a floor extension much higher than the average, with luxurious services or multiple floors, when all the other samples are only one-leveled units, it is a case to disregard.

4.7 Final results

Multiple Regression Analysis is a powerful tool for this study that helps give answers to the primary question: does *daylighting* have monetary value in the real estate?

Many models can be obtained through Multiple Regression, which yield different results: it is therefore important to compare which of the variables can be the most influential in the total cost. Some of the models found can also describe why one or more variables do not influence the price, or even can decrease it.

The comparison of different solution has been made considering some of the statistical indicators:

- the higher the *corrected determination index* (R_c^2) the better the model;
- the lower the *Akaike Criterion* the better the model;
- the lower the *Schwarz Criterion* the better the model.

When the best models have been found, the marginal coefficients of each variable were visible, with either a positive or a negative value. It is possible to understand the influence each of the variables has on the formation of the dependent variable (price per square meter) through the coefficients representing the implicit marginal prices. In concrete words, the final models can state how much influence the daylight variables have on the listing prices, both in positive and negative terms.

4.8 Summary

The study has used quantitative methodological approaches and quantitative research methods. The aim of this study has been to understand and to prove the importance of daylighting and its capacity of having monetarily value in the real estate. The workflow is composed by the definition of the setting and of the data sample, followed by the simulations on the 3D models of the residential units, and the Multiple Regression analysis with the introduction of new variables. Multiple ***green variables***, such as the average Daylight Factor and the spatial Daylight Autonomy, have been integrated into the Multiple Regression models and their significance have been tested. The best models have been interpreted at last.

Sitography Chapter 4

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Chapter 5
Data Sampling

5.1 Introduction

Data sampling is one of the most delicate parts of the research, where data (all variables to include) is collected and organized within the real estate market segment aimed for the study. Only after this step, the analysis can be carried on with Multiple Regression models. Not all variables analyzed in this Chapter can be included in the models, since they will present collinearity. Only the most meaningful variables will help in finding the most optimal result, which are the variables presenting the most differences along all the housing units.

5.2 Setting of this study

The study includes the analysis of the listing prices of units in the area of *Pozzo Strada*.
Pozzo Strada has been chosen since it consists of quite an extensive area that has been mostly developed after the wars and has kept increasing until nowadays, thanks to the presence of the metro stations. which links this area to the center of the city, to the two train stations, and all the way to Lingotto. *Pozzo Strada* comprehends various building typologies built over the past century, and to this day it is mostly a residential area. It presents a good infrastructure and two big green areas. *Pozzo Strada* was chosen because the perfect example of a residential peripheral area, that could guarantee widely available data to be included in the study, which couldn't have been easy to determine when analyzing more central areas, where the listing prices of units and their data availability

are very limited resulting in a non-significant sampling.
In order to start approaching the data sampling, it is necessary to take a step back and understand the historical development of this area. The area under study can be identified in different ways.

5.2.1 "District III" and *Pozzo Strada Borough*

For Turin's municipality, *Pozzo Strada* is in "**District III**"[167], which includes the areas of San Paolo "Borough"[168], *Pozzo Strada* "Borough", Cit Turin-Cenisia "Township"[169], and Lesna "Township". They represent the western area of Turin, which developed from the end of the XIX century and was mainly used for agricultural purposes, before the industrial development[170]. The terms "borough" and "township" both refer to peripheral areas, but while "boroughs" are ancient settlements formed in a rural context but maintaining their topology, "townships" originated in the XIX century and depending on the gates of the first toll fence[171], as well as along the road to access the city, without maintaining over time the original topology[172].
Pozzo Strada Borough iss the strategic area between Porta Segusina (Porta Susa station now), passing via Collegno and Grugliasco, and reaching Rivoli, where there used to be villas and agricultural units. The intensive cultivations were in proximity to the Dora Riparia River, which reached all the cultivations thanks to a system of canals[173]. As for Santa Rita and Mirafiori, starting from the second part of 1800, the old agricultural territorial asset was layered up with the peripheral urban tissue, after which only part of the architectural structure was preserved[174]. *Pozzo Strada* started losing the industrial asset gained, substituting it with multi-storey residential units. The exceptions are present along Corso Francia, where villas and palaces are seldom present, in particular Villa Tesoriera[175].
Cit Turin stands for *little Turin*[176] because it is the area that developed at the beginning of 1900 just outside the city walls, maintaining the orthogonal pattern of the historical center and characterized by many liberty-style units[177].

5.2.2 OMI Zones

OMI[178] is the Italian Real Estate Market Observatory, which periodically elaborates information regarding technical-economical housing values, which is then published each semester on the website of *Agenzia delle*

[167] *Circoscrizione III.*

[168] *Borgo.*

[169] *Borgata.*

[170] MuseoTorino, *Circoscrizione 3*, https://www.museotorino.it/view/s/e2284ef66b8e485a9d6625c2a5360b35.

[171] The first Cinta Daziaria of 1853-1912.

[172] PIA DAVICO, *et al.*, (2014) *La storia della città per capire il rilievo urbano per conoscere: borghi e borgate di Torino*, Torino, Politecnico di Torino, pp. 13, 17-18.

[173] (2000) *Circoscrizione III: San Paolo, Pozzo Strada, Cenisia, Cit Turin, Borgata Lesna*, Torino, CIttà di Torino, pp. 13-14.
[174] *ibidem*, p.17.

[175] PIA DAVICO, *et al.*, (2014) *La storia della città per capire il rilievo urbano per conoscere: borghi e borgate di Torino*, Torino, Politecnico di Torino, p. 207.

[176] "Piccola Torino"

[177] MuseoTorino, *Circoscrizione 3*, https://www.museotorino.it/view/s/e2284ef66b8e485a9d6625c2a5360b35.

[178] OMI: Osservatorio del Mercato Immobiliare.

Entrate[179]. OMI provides information for each homogeneous territorial area, not only about housing, but also parking spaces, and commercial ones. For the area selected it provides the geographic limit (*Figures 53-54*), as well as the quotations elaborated, which consist of minimum and maximum intervals, surface in € per square meter, divided by building typology and conservation state.

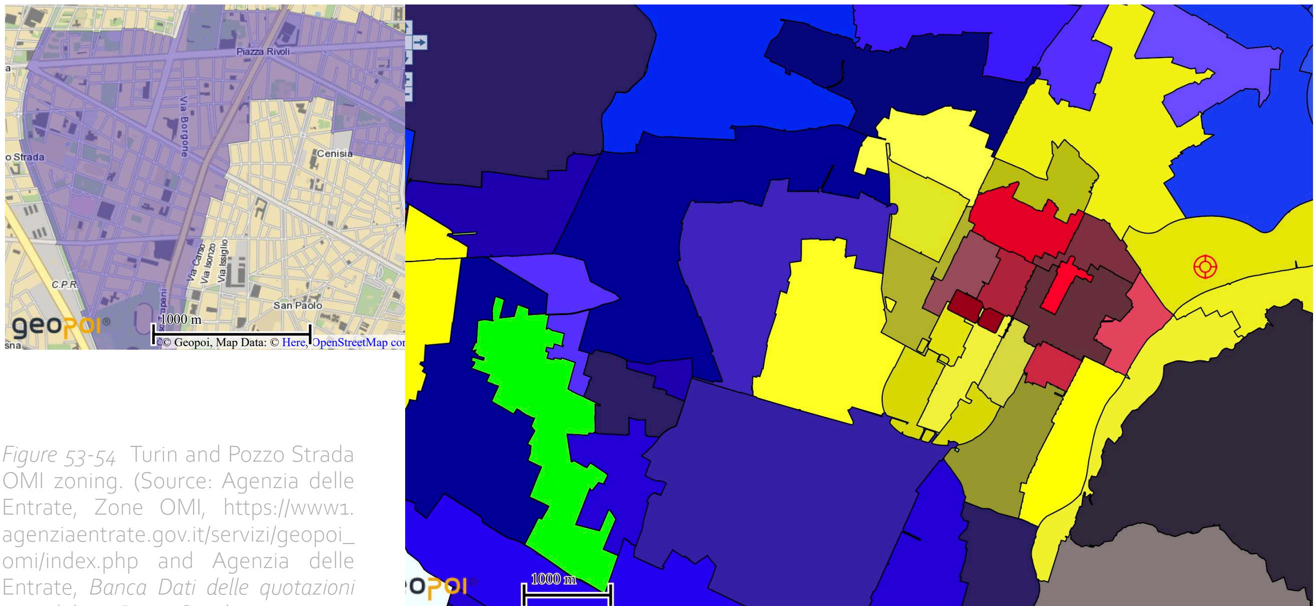


Figure 53-54 Turin and Pozzo Strada OMI zoning. (Source: Agenzia delle Entrate, Zone OMI, https://www1.agenziaentrate.gov.it/servizi/geopoi_omi/index.php and Agenzia delle Entrate, *Banca Dati delle quotazioni immobiliari - Pozzo Strada*, https://www1.agenziaentrate.gov.it/servizi/geopoi_omi/stampa.php?id=2157&pr=TO&co=L219&linkzona=TO00001069&idstrada=&anno_semestre=20222&fasciazona=Periferica/POZZO%20STRADA&utilizzo=Residenziale&codzona=D7&lingua=IT&bt1=Mostra%20valori&E=7.640448&N=45.068201).

The area ***Pozzo Strada*** is represented by **code D7** since 2018[180]. The listings of residential units vary from 1500 up to 3100 €/m², while the economic units range from 1300 €/m² up to 1900 €/m², always considering the gross surface (*Figure 55*). The rental values have here been discarded because they are not relevant to the current study.

Figure 55 Re-elaborated by the author. (Source: Agenzia delle Entrate, *Banca Dati delle quotazioni immobiliari - Pozzo Strada*, https://www1.agenziaentrate.gov.it/servizi/geopoi_omi/stampa.php?id=2157&pr=TO&co=L219&linkzona=TO00001069&idstrada=&anno_semestre=20222&fasciazona=Periferica/POZZO%20STRADA&utilizzo=Residenziale&codzona=D7&lingua=IT&bt1=Mostra%20valori&E=7.640448&N=45.068201).

Typology	Conservation state	Market Value (€/m²)	
		min	max
civil residences	normal	1450	2050
civil residences	optimal	1950	2900
economic residences	normal	1250	1850

179 Agenzia delle Entrate, *Banca Dati delle quotazioni immobiliari - Pozzo Strada*.

180 Microzone 32 (OICT) until 2018.

5.2.3 Turin's Microzones

The data provided by the Market Observatory of the city of Turin (OICT, *Osservatorio Immobiliare della città di Torino*) is limited to the year 2018, differentiating the used units, and the new or completely renovated housing units. Turin's Municipality had been divided into 40 Microzones in total (as shown in *Figure 45* in Chapter 3), which had been defined by Politecnico di Torino, Dipartimento Casa Città (from 2012 Department of Architecture and Design), and later approved by the **City Council on June 1999** according to DPR 138/98 and the Regulations issued by the Ministry of Finance. Each Microzone had been determined by the urban homogeneity as well as being part of a market segment, where the difference between minimal and maximum prices were limited to two times the difference[181]. The Microzones division of the territory was **valid until 2018**, after which only the OMI zones were used, although no differences in the perimeter were detected in the case of *Pozzo Strada*.

Pozzo Strada limitations includes corso Francia on the North, piazza Rivoli big intersection, corso Vittorio Emanuele II, corso Trapani, corso Peschiera, corso Monte Cucco. Thanks to the good infrastructure it presents, it is the perfect example of a residential district, with good services and two green spaces, Parco Ruffini in the South, and Parco della Tesoriera in the North (*Figure 56*).

[181] OICT Osservatorio Immobiliare Città di Torino, *Cosa sono le Micro-zone*, http://www.oict.polito.it/micro-zone_e_valori/cosa_sono_le_micro-zone.

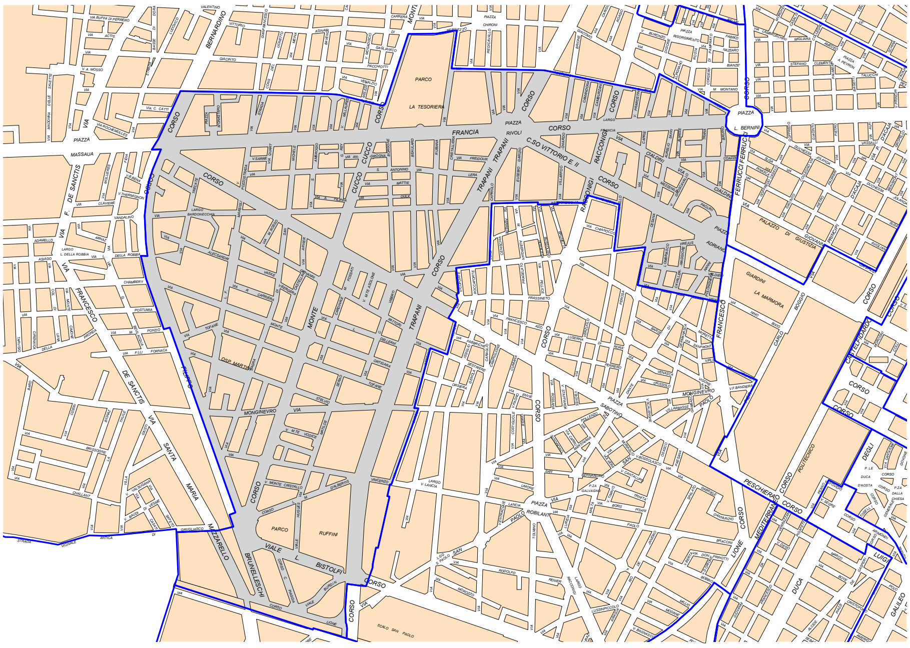
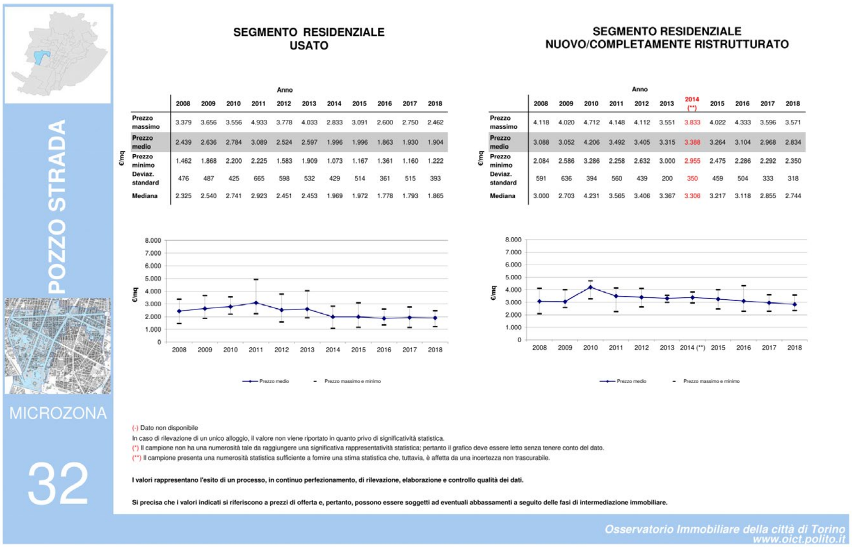


Figure 56 Microzone 32, Pozzo Strada, in detail. (Source: OICT Osservatorio Immobiliare Città di Torino, *Microzona 32*, http://www.oict.polito.it/content/download/122/666/version/26/file/microzona32.pdf).

The average price of *€/m²* of used units (left of *Figure 57*) has undergone an increase from 2008 to 2011, after which it decreased until reaching a stable level below 2000 *€/m²* in the years 2014 to 2018. Regarding new or freshly renovated units (right of *Figure 57*), the peak of the average price of *€/m²* happened in 2010, after which it slowly decreased reaching the lowest point in 2018.



POZZO STRADA

SEGMENTO RESIDENZIALE
USATO

€/mq	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Prezzo massimo	3.379	3.656	3.556	4.933	3.778	4.033	2.833	3.091	2.600	2.750	2.462
Prezzo medio	2.439	2.636	2.784	3.089	2.524	2.597	1.996	1.996	1.863	1.930	1.904
Prezzo minimo	1.462	1.868	2.200	2.225	1.583	1.909	1.073	1.167	1.361	1.160	1.222
Deviaz. standard	476	487	425	665	598	532	429	514	361	515	393
Mediana	2.325	2.540	2.741	2.923	2.451	2.453	1.969	1.972	1.778	1.793	1.865

SEGMENTO RESIDENZIALE
NUOVO/COMPLETAMENTE RISTRUTTURATO

€/mq	2008	2009	2010	2011	2012	2013	2014 (**)	2015	2016	2017	2018
Prezzo massimo	4.118	4.020	4.712	4.148	4.112	3.551	3.833	4.022	4.333	3.596	3.571
Prezzo medio	3.088	3.052	4.206	3.492	3.405	3.315	3.388	3.264	3.104	2.968	2.834
Prezzo minimo	2.084	2.586	3.286	2.258	2.632	3.000	2.955	2.475	2.286	2.292	2.350
Deviaz. standard	591	636	394	560	439	200	350	459	504	333	318
Mediana	3.000	2.703	4.231	3.565	3.406	3.367	3.306	3.217	3.118	2.855	2.744

MICROZONA

32

(-) Dato non disponibile
In caso di rilevazione di un unico alloggio, il valore non viene riportato in quanto privo di significatività statistica.
(*) Il campione non ha una numerosità tale da raggiungere una significativa rappresentatività statistica; pertanto il grafico deve essere letto senza tenere conto del dato.
(**) Il campione presenta una numerosità statistica sufficiente a fornire una stima statistica che, tuttavia, è affetta da una incertezza non trascurabile.

I valori rappresentano l'esito di un processo, in continuo perfezionamento, di rilevazione, elaborazione e controllo qualità dei dati.

Si precisa che i valori indicati si riferiscono a prezzi di offerta e, pertanto, possono essere soggetti ad eventuali abbassamenti a seguito delle fasi di intermediazione immobiliare.

Osservatorio Immobiliare della città di Torino
www.oict.polito.it

Figure 57 Values details in the years 2008-2018 of Microzone 32 - *Pozzo Strada*. (Source: OICT Osservatorio Immobiliare Città di Torino, Microzona 32, http://www.oict.polito.it/content/download/122/665/version/26/file/Microzona_32.pdf).

It is necessary to state that these data could now be considered outdated, but they have still been considered for a first analysis of the area of *Pozzo Strada*. In fact, market prices are part of a constant process of monitoring, since it fluctuates constantly also within the same year. This is the reason why the *observatories* elaborates data each semester, in order to keep the data updated and to keep the data quality controlled.

5.3 Explanation of Variables

After having selected the setting, the data sampling can start. All variables to be included in the study need to be organized properly. The variables are features of each of the housing units considered. In order to obtain a good result, the sample needs to be in a significant number, so a total of **100 housing units** in the area *Pozzo Strada* have been selected.

All the variables to be included in the data sampling can be both **quantitative** and **qualitative**, but to undergo the regression analysis they need to be always transformed in quantities.

Quantitative variables use a cardinal measuring scale and can be **discrete** (counting) or **continuous** (measurement).

Qualitative variables use a nominal measuring scale, an ordinal measuring scale, or an interval scale, and can be **ordinal** (sorting) or **categorical** (classification) (*Figure 58*).

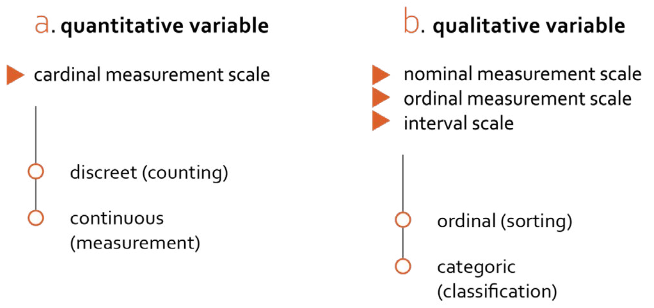


Figure 58 Quantitative and qualitative variables. (Source: Elaboration by the author).

The quantitative numerical variables use numerical attributes indicating a quantity with absolute zero as the origin. It has a discrete scale when variables refer to the number of rooms, balconies, and bathrooms. It has a continuous scale for example in the case of listing prices in euros (€), as well as in euros per square meter (*€/m²*) values. The qualitative nominal variables aim at describing the quality of the object, without order, but only by classifying without ambiguity. As reported in the studies included in the previous chapters, the **setting** is often resulting as a very significant variable, especially when dealing with a high number of data, but in this study the location of the data sample is within the same Municipality (Turin) and the same zone (*Pozzo Strada*, D7), so it is not expected to be particularly significant. The ordinal scale attributes to the categories of the variables but in a meaningful order, for example in the case of Noise Pollution 1 stands for "very light", 2 for "medium", and 3 for "very high" noise pollution. In both ordinal and categorical scales, when only two variables are considered they are defined as **dichotomic**. If the elevator is present 1 is assigned, when absent, 0.

Figure 59 presents the summary of all the variables that will be included in the study and later in this Chapter will be singularly developed.

	Data structure	Data content	Data Value - Vocabulary	Data Source
i. location				
	IDAP	Identification of the unit, Apartment ID	Open	Author
	Link	Link of the advertisement	Open	www.immobiliare.it
	Municipality	Turin	Closed	Author
	Area	D7 - Pozzo Strada	Closed	OMI
	Date	Date of advertisement	Open	www.immobiliare.it
	Address	Address of the unit	Open	www.immobiliare.it
	Coordinates	Coordinates of the unit	Open	www.googlemaps.com
ii. context				
	Building typology	Typologies of residential units	Closed	www.immobiliare.it
	Facade typology	Historical - Architectural typology	Closed	Author
	Price	Listing price (€)	Open	www.immobiliare.it
	Surface	Commercial surface (m^2)	Open	www.immobiliare.it
	Price/m^2	Price per square meter (€/m^2)	Open	www.immobiliare.it
	Floor of the unit	Floor	Open	www.immobiliare.it
	Total number of floors	Total number of floors of the building	Open	www.immobiliare.it
	Last floor	Last floor of the building	Closed	Author
	Floors	Floors of the apartment	Closed	Author
	Year of construction	Year of construction	Closed	www.immobiliare.it, Geoportale
	Building category	Category of the building	Closed	www.immobiliare.it
	State of conservation of the unit	State of conservation of the unit	Closed	www.immobiliare.it
	Elevator	Presence of the elevator	Closed	www.immobiliare.it
	Green Area	Presence of the green area	Closed	www.immobiliare.it
	View out	Levels of quality of the view	Closed	Author
iii. noise pollution				
	Daily Noise Pollution	Noise pollution on the streets based on Arpa	Closed	Arpa
	Nocturnal Noise Pollution	Noise pollution on the streets based on Arpa	Closed	Arpa
	Average Noise Pollution	Noise pollution on the streets based on Arpa	Closed	Arpa
iv. apartment layout				
	Number of rooms	Number of rooms	Open	www.immobiliare.it
	Bathrooms	Number of bathrooms	Open	www.immobiliare.it
	Kitchen	Typology	Closed	www.immobiliare.it
	Balconies	Number of balconies (depth <1.40m)	Open	www.immobiliare.it
	Terraces	Number of terraces (depth >1.40m)	Open	www.immobiliare.it
v. daylight				
	Orientation	Orientation of the apartment	Closed	Author
	Views	Number of views	Closed	www.immobiliare.it
	Glazing	Type of glazing	Closed	www.immobiliare.it
	Window Frame	Frame Typology	Closed	Author

Figure 59a Variables considered in this study, in black the ones present in literature, in orange the ones introduced for this study. (Source: Elaboration by the author).

Data structure		Data content	Data Value	Data Source
vi. daylight simulations with and without obstructions				
	WFR	Window to Floor ratio > 1/8	Closed	Author (Rhinoceros7, Climate Studio)
	DFm % all apartment/ regularly occupied area	average Daylight Factor of the entire apartment	Closed	Author (Rhinoceros7, Climate Studio)
	median DF % median	median Daylight Factor of the entire apartment	Closed	Author (Rhinoceros7, Climate Studio)
	Spatial Daylight Autonomy sDA300,50% regularly occupied area	% of the area with minimum 300 lx for 50% of the year	Closed	Author (Rhinoceros7, Climate Studio)
	Annual Sunlight Exposure ASE1000,250h regularly occupied area	1000lux for at least 250h per year	Closed	Author (Rhinoceros7, Climate Studio)
	Useful Daylight Illuminance	UDI.f (fell-short)	Closed	Author (Rhinoceros7, Climate Studio)
	Useful Daylight Illuminance	UDI.a (achieved)	Closed	Author (Rhinoceros7, Climate Studio)
	Useful Daylight Illuminance	UDI.e (exceeded)	Closed	Author (Rhinoceros7, Climate Studio)
	Average Illuminance	Average Illuminance (lux)	Closed	Author (Rhinoceros7, Climate Studio)
	Blinds closed	% of blinds being used (to aovid glare, overheating)	Closed	Author (Rhinoceros7, Climate Studio)
	Sky View Factor on facades weighted for all facades with significant openings	Sky View Factor for each facade (%)	Closed	Author (Rhinoceros7, Climate Studio)
vii. energy efficiency				
	Energy performance of the building	EPBD (APE)	Closed	www.immobiliare.it
	Heating typology	Heating typology	Closed	www.immobiliare.it
	Heating system typology	Heating system typology	Closed	www.immobiliare.it
	Heating source	Source typology	Closed	www.immobiliare.it
	Cooling	Cooling	Closed	www.immobiliare.it

Figure 59b Variables considered in this study, in black the ones present in literature, in orange the ones introduced for this study. (Source: Elaboration by the author).

5.3.1 Location

5.3.1.1 Apartment ID

The identification of the data sample consists of a total of **100 case studies**. The discrete counting variable aims to organize the whole data sample by assigning to each unit a number. The variable is quantitative (numerical continuous), using a cardinal scale starting from 1 up to 100 and it has been assigned with a random observation.

5.3.1.2 Link

The link to the advertisement is a nominal variable that can be used to trace back the source. Since the study focuses on the listing prices of residential units, the links are temporarily available, for this reason along with the research all the information provided has been categorized as follows, as well as all the images provided have been saved and assigned according to the ID Apartment. The text of the advertisement has also been reported in the spreadsheet to have it always available. The website used for this study is *www.immobiliare.it*.

5.3.1.3 Municipality

The municipality included in the study is nominal and it is always Turin.

5.3.1.4 Area

The area considered is *Pozzo Strada*, in the data sample defined with code D7 by Agenzia delle Entrate, which includes both the areas known as *Pozzo Strada* itself and Cenisia. The area is subdivided into three micro areas, known as Rivoli, in the proximity of Piazza Rivoli; Monte Cucco – Bardonecchia, and finally Ruffini, representing the area closeby to Park Ruffini. These three micro areas are represented by a qualitative variable, using a nominal descriptive scale, where 1 stands for **Rivoli**, 2 for **Monte Cucco - Bardonecchia**, and finally 3 for **Ruffini** (*Figure 60*).

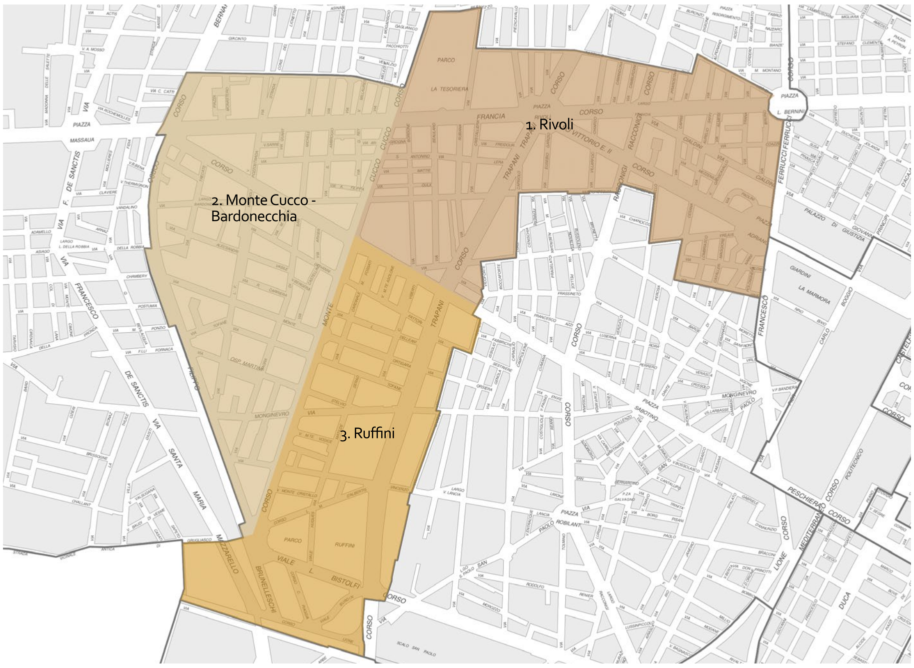


Figure 60 The 3 Micro-Areas of *Pozzo Strada*. (Source: Elaboration by the author).

The data sample collected shows 46 units in Rivoli, 34 in Monte Cucco - Bardonecchia, and finally 20 in Ruffini. The inequality is explained by the different dimensions of the micro areas, as well as the different destinations of uses of it. For example, in the case of the micro-area Ruffini, it's clear that the presence of the park influences the lower units found, as well as it being the smallest area (27% of the total *Pozzo Strada*). Rivoli is the zone with more units considered and also the bigger in size with 39%, followed by Monte Cucco - Bardonecchia with 34% of the total area (*Figure 61*).

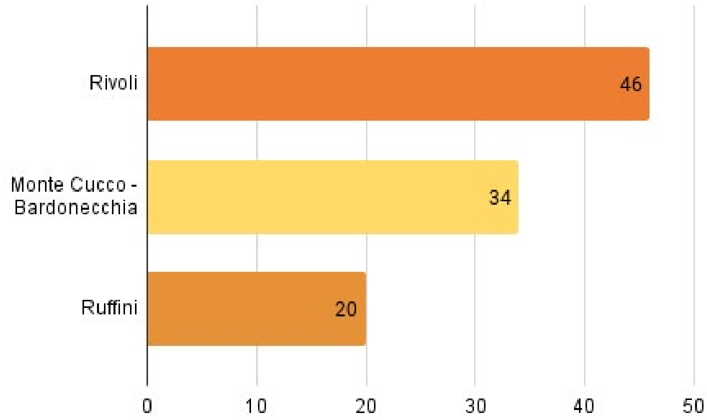


Figure 61 Graph depicting the data collection in the three Sub-Zones. (Source: Elaboration by the author).

5.3.1.5 Date

The market values are dynamic and highly influenced by inflation over time, for this reason only advertisements published in the last trimester of the year 2022 have been considered. The dates of the advertisements go from 04/10/2022 up to 12/12/2022. It is an ordinal variable. It is important to note that it is not given the amount of time a unit has been on the market and the possibility of re-posting the advertisement over time.

5.3.1.6 Address and Coordinates

The address of the unit has been reported and it's a nominal variable, while the coordinates of each unit are ordinal variables. The coordinates of the unit are listed in order to create a map with *QGIS* and to verify the correct location within the limits prescribed by the zone under study (*Figure 62*).

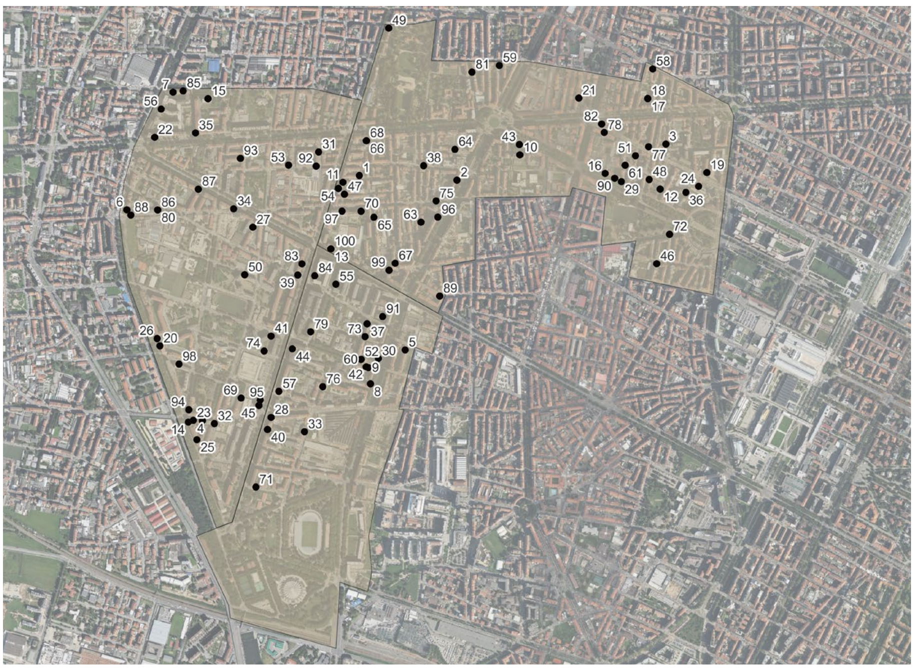


Figure 62 QGIS result of the map with all the settings of the units considered in the study. (Source: Elaboration by the author).

5.3.2 Context

5.3.2.1 Listing Price and Surface

The listing price is the price found in the advertisement. It is not given to know the actual selling price of the unit by buyers, which could decrease or increase depending on the single case. The listing price of the unit is euros (€), the commercial surface is in square meters (*m^2*) and the price per square meter is also being calculated (*€/m^2*). These variables are all quantitative and continuous.

The listing price varies between a maximum of **€419.000** and a minimum of **€49.000**, and the surface varies from **25** m^2 up to **177** m^2, reaching values up to 3.103 €/m^2 (*Figures 63-64*).

	PRICE *(€)*	**SURFACE** *(m^2)*	**PRICE/m^2** *(€/m^2)*
Max	419000	177	3103,703
Average	187340	92,840	1983,622
Min	49000	25	750
Stand. Dev.	92675,846	32,254	502,096
Median	162000	81,500	1970,862

Figure 63 Maximum, average, minimum, standard deviation, and median of the listing price, surface, and their ratio. (Source: Elaboration by the author).

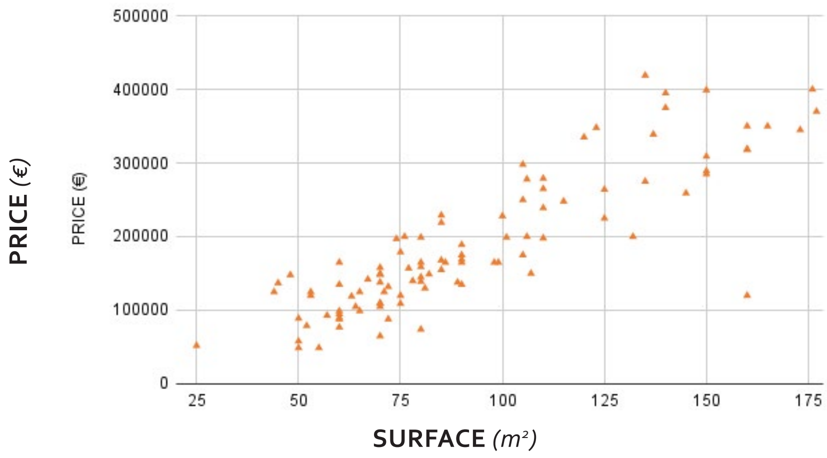


Figure 64 Listing Prices graph in euros *(€)* and surface *(m^2)*. (Source: Elaboration by the author).

5.3.2.2 Building Typology

The building typology categorizes the residential units mainly in three ways: "*a ballatoio*", plurifamily, and multi-storey. It's important to notify there are more building typologies, but for the research, they have not been considered because they are not present in significant numbers or even not present at all, such as in the cases of villas.

"*A ballatoio*" is a typical Turin housing where the staircase is often left open on the sides and faces the courtyard, as well as the entrance to the units, helped by a balcony that runs along the whole façade.

The plurifamily building is composed of 4 to 6 units, while the multi-storey overcomes that last number with no limitation.

The variable used to describe them is qualitative ordinal. The 1 corresponds to the typology '"a ballatoio"', 2 to the 'plurifamily' and 3 to the 'multi-storey'. The order is significant because it is linked to other variables such as the construction year, and the quality of construction typology, in a way that the more the number increases, *the higher the quality of the unit.*

As a result, it's interesting to notice the majority of the units are classified in 'multi-storey' (94), against the 5 'plurifamily' units and only 4 '"a ballatoio"', depicting a homogeneity in this area of the city (*Figure 65*).

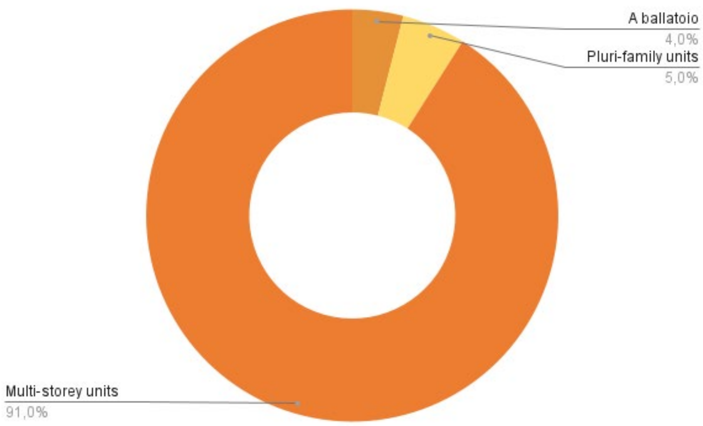


Figure 65 Building typology graph showing the Multi-Storey units prevailing. (Source: Elaboration by the author).

5.3.2.3 Façade Typology

Given the topic of the research, the introduction of new variables have been a necessity. To determine the *natural light* entering indoors in the units under consideration, the opening typologies on the façade have been categorized, according to the rhythm, shapes, and sizes. It's important to clarify that no historical meaning has been considered for the explanation of this ordinal scale qualitative variable.

The façade typology has been divided into four categories:

1. The **simple** façade of typology 1 is very common, and as with other typologies it presents a different ground floor in terms of materiality as well as rhythm (*Figures 66-67-68*). It presents a predominant verticalism and only a few balconies, without varying shape or dimensions, giving volume to it. The floor height is between 2.7 meters and 3.0.

Figure 66-67-68 Façades of units 8, 6, and 9 (from left to right). (Source: https://www.immobiliare.it/annunci).

2. The **articulated** façades of the second typology recall the simplicity of the first typology, whilst being richly decorated in the railings of the balconies, and in the window cornices (*Figures 69-70-71*). The floor's height can rise up to 3.5m.

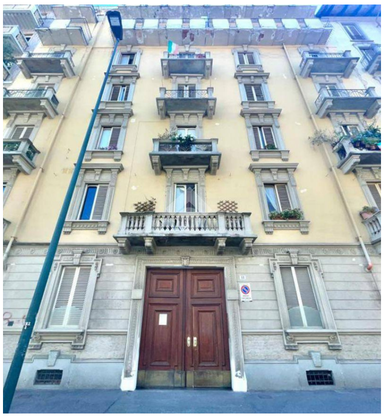
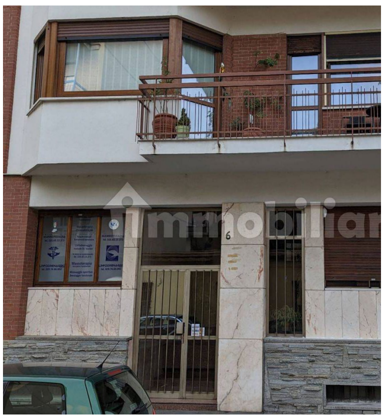


Figure 69-70-71 Façades of units 24, 58, and 82 (from left to right). (Source: https://www.immobiliare.it/annunci).

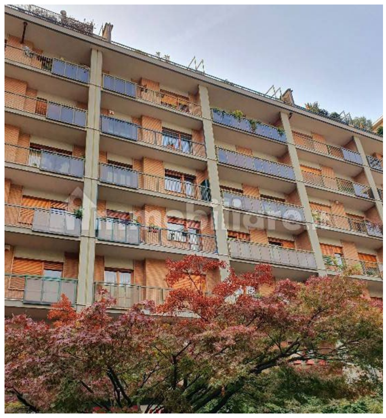
Figure 72-73-74 Façades of units 61, 51, and 14 (from left to right). (Source: https://www.immobiliare.it/annunci).

3. The third category is characterized by the predominance of horizontalism, with a variety of balconies, loggias, and terraces that brings **dynamicity** to the volume of the building. The openings are highlighted by horizontal stripes given by different materials or highlighting the floor slabs (*Figures 72-73-74*).



4. The last typology is composed of balconies and terraces that run along the whole façade, creating a more **imposing** appearance, usually with open plan ground floors and lots of green and trees, facing the main corso (*Figures 75-76-77*).

Figure 75-76-77 Façades of units 10, 56, and 70 (from left to right). (Source: https://www.immobiliare.it/annunci).



As a result, 36 are the units in the first typology, only 8 in the second (being it almost a subcategory of the first), 41 in the third, and only 15 in the last (*Figure 78*). It shows the variety of units in terms of fenestration, thus still excluding important elements such as the presence of obstruction and the type of glazing and frame, as well as values of daylight effectively entering into the space, which will all be quantified later on with another set of variables. The variable is qualitative ordinal, since increasing the category number increases the number of openings thus having the possibility of more natural light to enter into the unit.

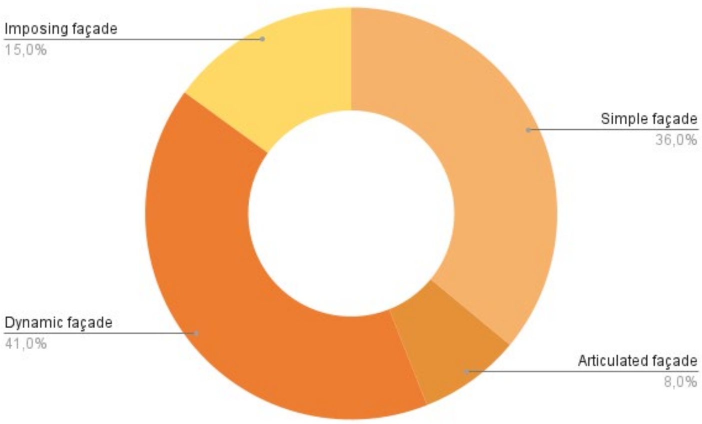


Figure 78 Graph showing façades typologies. (Source: Elaboration by the author).

5.3.2.4 Floor Allocation

The floor corresponds to the unit's floor allocation as a quantitative numerical continuous variable, spacing from ground 0 up to floor 9. In ground 0 also the mezzanine floor has been included for simplicity. 12 units are at the ground or mezzanine floor, 21 units are at the first level above ground, followed by 14 units at the second level (*Figure 79*). This shows also on the graph that the upper floors are less common in the data sample.

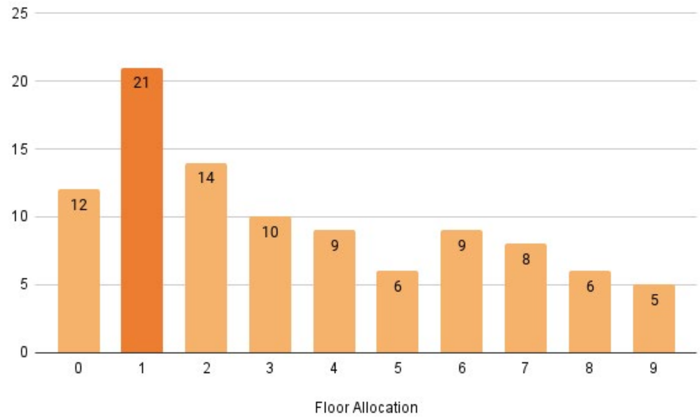


Figure 79 Graph showing floor allocation of the units, from left to right, from the ground floor up to 9 floors. (Source: Elaboration by the author).

The total number of floors represents all the above-ground floors, including ground floors and mansards, whilst excluding the basement. The values go from 0 up to 11 floors in total (*Figure 80*).

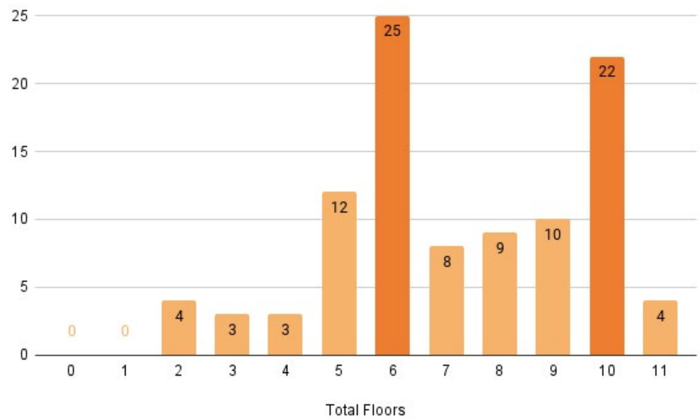


Figure 80 Graph showing the total floor of the building where units are set. (Source: Elaboration by the author).

The indication of the last floor is reported as a qualitative nominal descriptive dichotomic variable, where 0 stands for 'no' and 1 for 'yes'. The result shows 20 of the units on the last floor (*Figure 81*). As long as it can be considered a good quality, it is of course not an interesting result by itself, since the value of a building on the second and last floor is not the same as a unit on the last floor of a 9-storey high building.

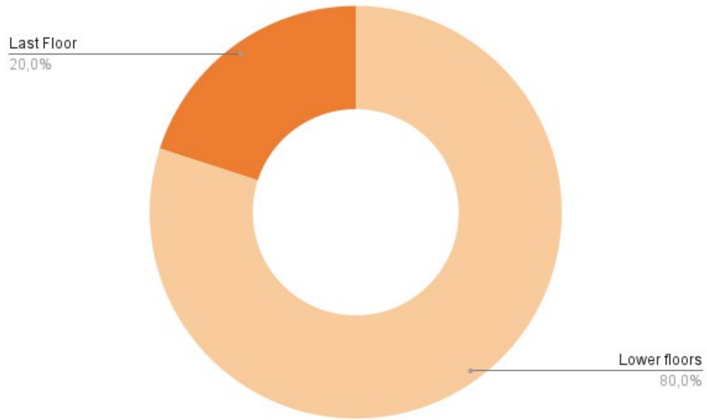


Figure 81 Graph showing the units allocated on the last floor of the building. (Source: Elaboration by the author).

An additional qualitative ordinal variable has been added later on during the research for dividing the floor of the units between 'floor 0 or mezzanine' (1), 'intermediate floor' (2), and 'last floor and mansard' (3), in order to summarize the floor value. As a result, 68 of the cases happen to be in the intermediate floor (*Figure 82*).

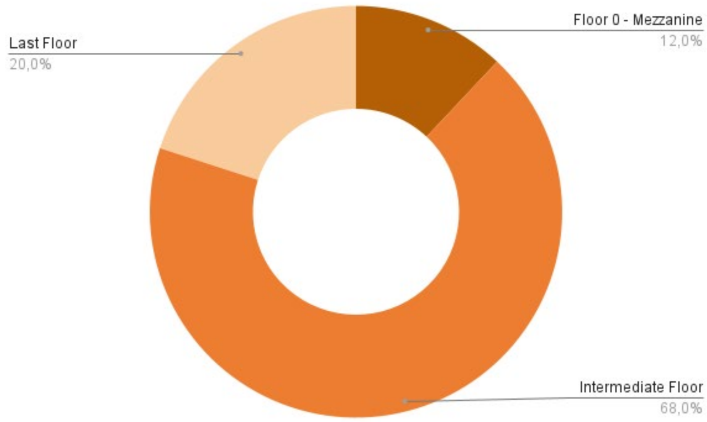


Figure 82 Graph showing floor allocation of the units in three typologies. (Source: Elaboration by the author).

5.3.2.5 Construction Year

The construction year has been divided into bands:

1. 1919-1945
2. 1946-1960
3. 1961-1990
4. 1990-2000
5. After 2000

The sample depicts 28 of the units in Category 2, and 59 of the units in Category 3, meaning most buildings have been built between 1946 and 1990, which corresponds to the years of the residential expansion of the area under study, while the buildings realized after 2000 are only 3 (*Figure*

83). The qualitative ordinal variable is directly linked to the classes in APE[182], meaning that the lower classes are expected due to the outdated building, unless recently renovated in order to achieve a better index.

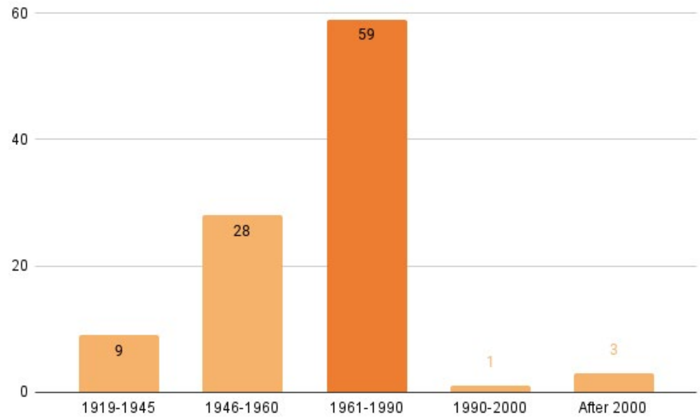


Figure 83 Graph showing floor allocation of the units in three typologies. (Source: Elaboration by the author).

5.3.2.6 Building Categories

The building categories have been summed up by:

1. Popular - Economic
2. Medium
3. Lordly – Precious

In 7 out of the 100, no building category has been detected from the advertisement, so they have been assigned a 0. Only 4 units correspond to 'popular-economic', while the 'medium' units are 49, against the 40 of 'lordly-precious' character (*Figure 84*). The variable is qualitative ordinal.

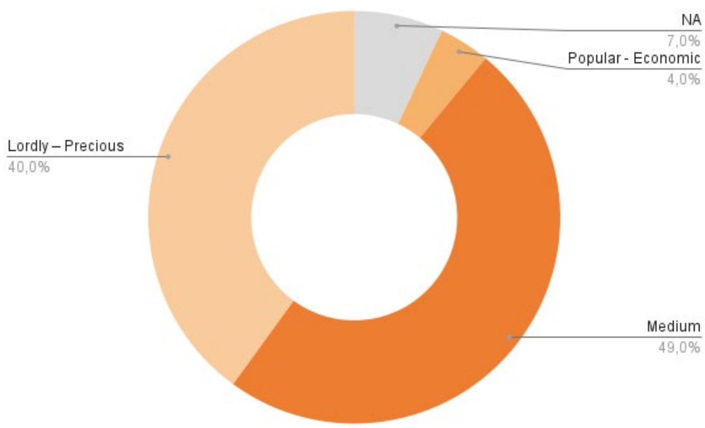


Figure 84 Graph showing the building categories. (Source: Elaboration by the author).

5.3.2.7 Conservation State

The conservation state has been divided into four main categories:

1. To be renovated (both partially and totally)
2. Good condition and habitable

[182] *Attestato di Prestazione Energetica*, Energy Performance of the Building (indicator).

3. Excellent condition and renovated

No freshly built buildings have been considered in this study, since it represents a market by itself. It's a qualitative ordinal variable where the higher the conservation state, the more compliance with the new and most updated regulations the unit. Only 8 are the apartments that need a renovation, while the majority divides between habitable (51) and renovated (41) (*Figure 85*)

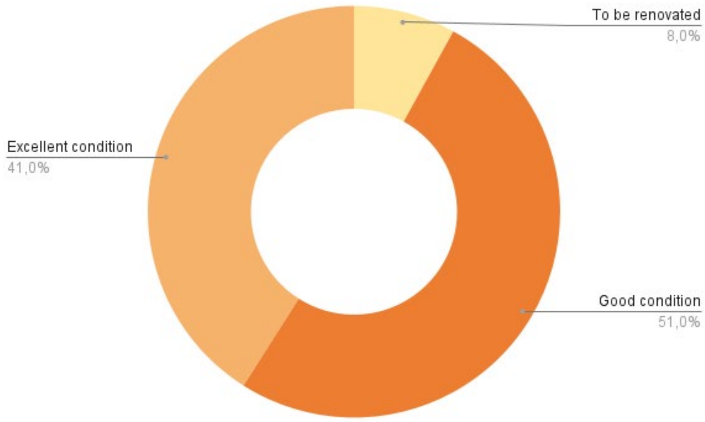


Figure 85 Graph showing the conservation state of the units. (Source: Elaboration by the author).

5.3.2.8 Elevator and Green Area

The presence of the elevator and the green areas have been detected. 82 of the apartments considered present at least one elevator (*Figure 86*), and only 34, instead, have the quality of a green courtyard and/or greenery on the ground floor of the building (*Figure 87*). They are both qualitative dichotomic variables.

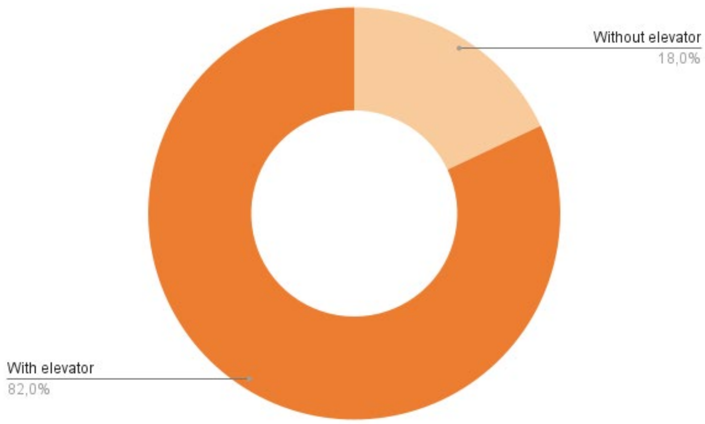


Figure 86 Graph showing the presence of the elevator. (Source: Elaboration by the author).

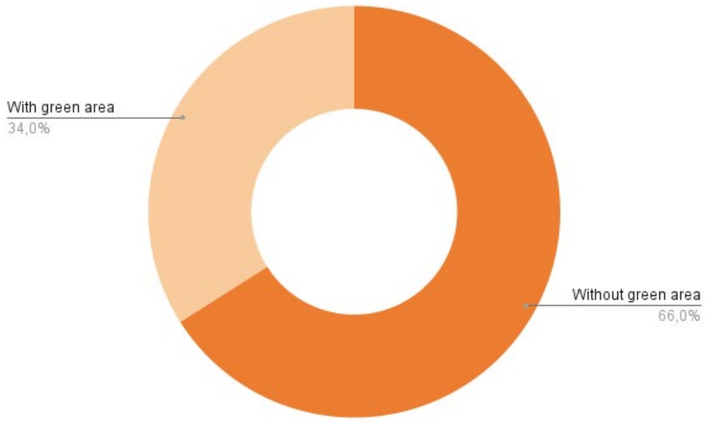


Figure 87 Graph showing the presence of a green area. (Source: Elaboration by the author).

5.3.2.9 View Out

The view out has already been treated in Chapter 2, since it is being discussed extensively in *EN17037:2018 - Daylight in Buildings.* From the regulation, the quality of the views has been identified in three categories for this qualitative ordinal variable. In the case of multiple openings, the view with the most relevant view has been considered.

1. The first category is characterized by **one landscape layer** only (urban and/or nature). Some examples are the views towards garages, walls, and secondary streets, and generally, the units are on the lower floors (*Figure 88*).

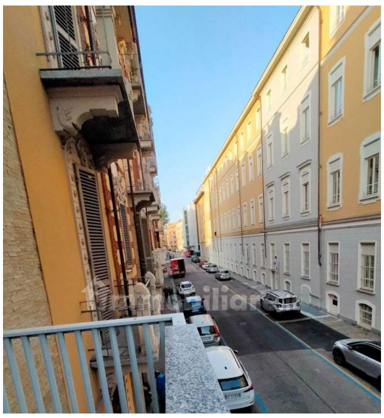


Figure 88 Example of landscape layer for unit 19. (Source: https://www.immobiliare.it/annunci).

2. For the second category, the **landscape layer** is accompanied by a **sky or terrain layer**, present mostly on medium floors and facing green as parks, or avenues (*Figure 89*).

Figure 89 Example of landscape and sky or terrain layer for unit 12. (Source: https://www.immobiliare.it/annunci).

3. Lastly, **all layers** are visible thanks to a higher height with a wide view of the whole city and its surroundings (*Figure 90*).

Figure 90 Example of all visible layers for unit 95. (Source: https://www.immobiliare.it/annunci).

42 units have at least one view where all layers are visible, followed by 32 where two layers are visible, and finishing with 26 which present only one layer visible due to the lower floor allocation (*Figure 91*).

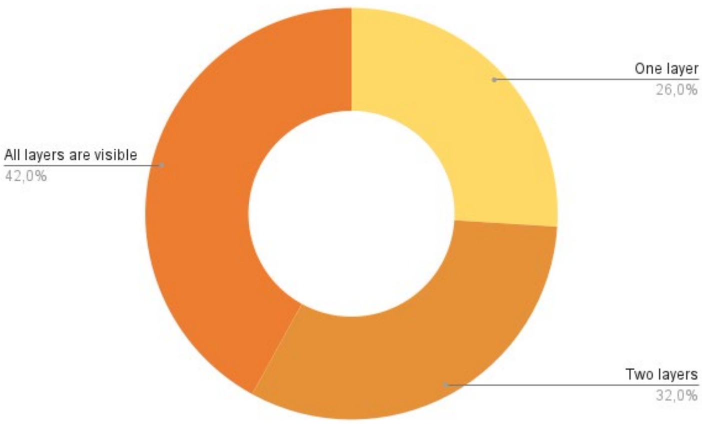


Figure 91 Graph showing the 3 Categories of "View Out" variable. (Source: Elaboration by the author).

5.3.3 Noise Pollution

5.3.3.1 Daily, Nocturnal, and Average Noise Pollution

The noise pollution data have been taken from Turin's Municipality website[183], where the data has been published in 2012 and hasn't been updated publicly yet. The maps published are divided into Districts (*Circoscrizioni*) (*Figure 92*).

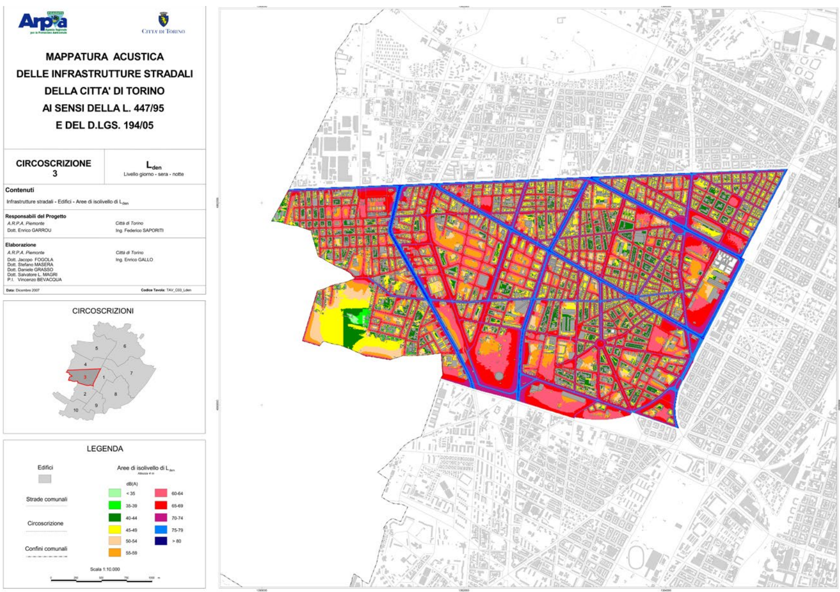


Figure 92 Example of map of District 3 showing the noise pollution levels in the average level (daily and nocturnal average). (Source: Comune di Torino, *Mappatura Acustica: Circoscrizione 3, Lden*, http://www.comune.torino.it/ambiente/bm~doc/tav_c03_lden.pdf).

The three levels of qualitative ordinal variables considered have been summed up and are classified as:

1. 'Very high' noise pollution if between 65 and >80 dB(A);
2. 'Medium' noise pollution when between 50 and 64 dB(A);
3. 'Very light' noise pollution for intervals <35 and 49 dB(A).

These three levels have been considered for three scenarios:

1. The daily level is between 6 a.m. and 22 p.m.;
2. The night level is between 22 p.m. and 6 a.m.;
3. The average level LDEN follows the European directives including day, evening, and night time.

Considering the average level (3), 69 of the units are classified in Category 1, while only 5 are in Category 3 (*Figures 93-94*). Only a handful are the units in Category 3, hence the 'very light' noise pollution level, in daily, night and average noise pollution scenarios, meaning they are located in secondary streets, or in inner courtyards, while the vast majority are facing or in the close

[183] Comune di Torino, *La Mappatura Acustica*, http://www.comune.torino.it/ambiente/rumore/mappatura-acustica/index.shtml.

proximity to the big avenues where noise pollution is higher. The level of noise pollution is calculated in relation to the same level allocation for all the units, meaning that the floor level is not considered.

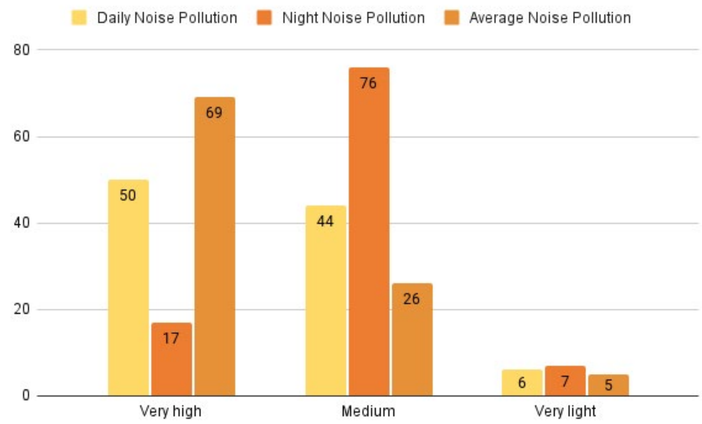


Figure 93 Graph showing the 3 Categories of Noise Pollution in relation to daily, night and average levels. (Source: Elaboration by the author).

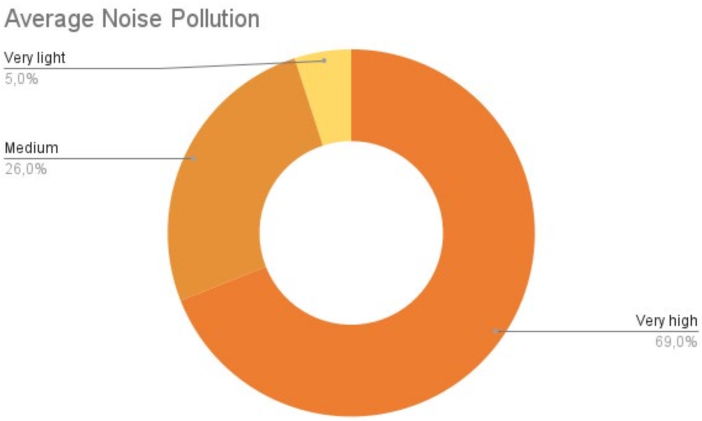


Figure 94 Graph showing the average Noise Pollution level with 69 units in Category 1. (Source: Elaboration by the author).

5.3.4 Apartment Layout

5.3.4.1 Number of Rooms

The numerical discrete variable of the number of rooms does not consider bathrooms, halls, and other service spaces, instead, it covers all the regularly occupied areas such as the kitchen, living room, study, and bedrooms. The units vary between 1 up to 6 rooms, with the vast majority of 63 units between three and four rooms (*Figure 95*).

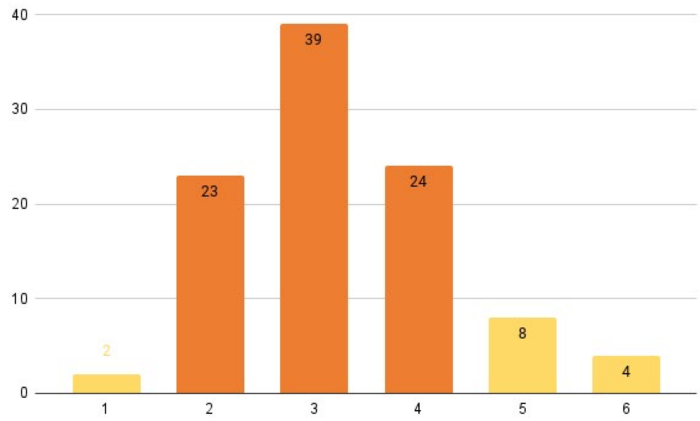


Figure 95 Graph showing the number of regularly occupied rooms of the units. (Source: Elaboration by the author).

5.3.4.2 Bathrooms

The number of bathrooms is another numerical discrete variable, spacing from one up to three bathrooms. In the case of 73 of the units the bathroom present is only one (*Figure 96*).

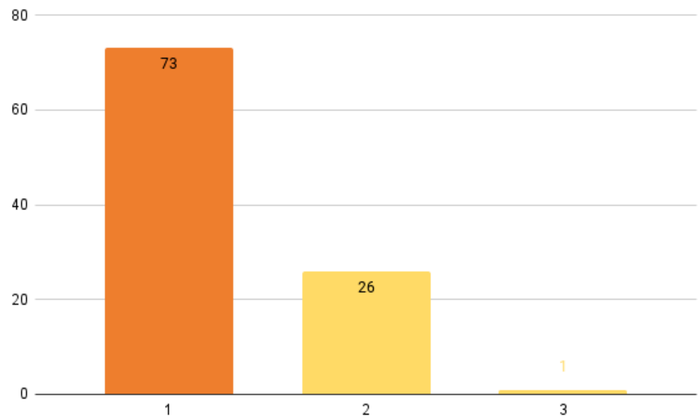


Figure 96 Graph showing the number of bathrooms present in the units. (Source: Elaboration by the author).

5.3.4.3 Kitchen

The kitchen typology is a qualitative ordinal variable and is divided as it follows:

1. **Kitchen corner** in the case of open space to the dining table and living space (22 units), typical in smaller units where the cooking, dining and living area are conjoined (*Figure 97*).

Figure 97 Example of kitchen corner in unit 1. (Source: https://www.immobiliare.it/annunci).

2. **Kitchenette** when the kitchen is present in a small separate room (30 units) (*Figure 98*).

Figure 98 Example of kitchenette in unit 5. (Source: https://www.immobiliare.it/annunci/).

3. **Semi-habitable** if there is enough space for at least the breakfast area (28 units), but with another area dedicated to the dining function (*Figure 99*).

Figure 99 Example of semi-habitable kitchen in unit 7. (Source: https://www.immobiliare.it/annunci).

4. **Habitable** when the kitchen has enough space for the dining table (20 units) (*Figure 100*).

Figure 100 Example of habitable kitchen in unit 25. (Source: https://www.immobiliare.it/annunci).

As a result, the kitchen typologies are well represented by the four categories above mentioned, with 30 cases with kitchenette (*Figure 101*).

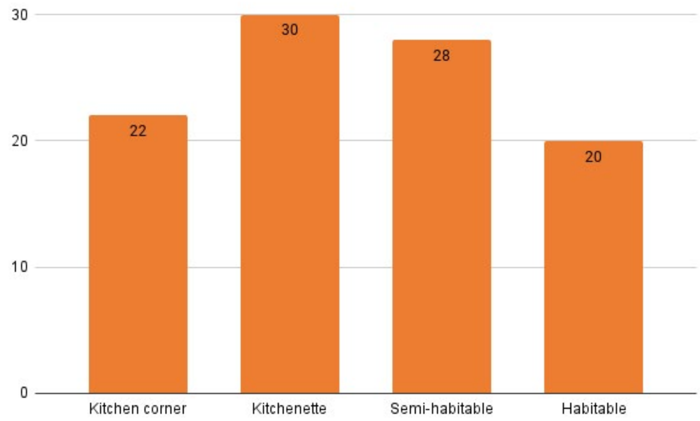


Figure 101 Graph showing the kitchen typologies. (Source: Elaboration by the author).

5.3.4.4 Balconies and Terraces

The number of balconies[184] and terraces[185] have been considered in this variable. For simplification also verandas have been included in these two categories. Balconies and terraces are first being included in the data sample as numerical discrete variable:

- 1 or 2 Balconies are present in the total of 75 units (*Figure 102*);
- in 20 units there is 1 Terrace (*Figure 103*).

[184] The balcony has been counted if the space is below 1,40 m in width.

[185] The terrace has been counted if the space is higher than 1,40 m in width.

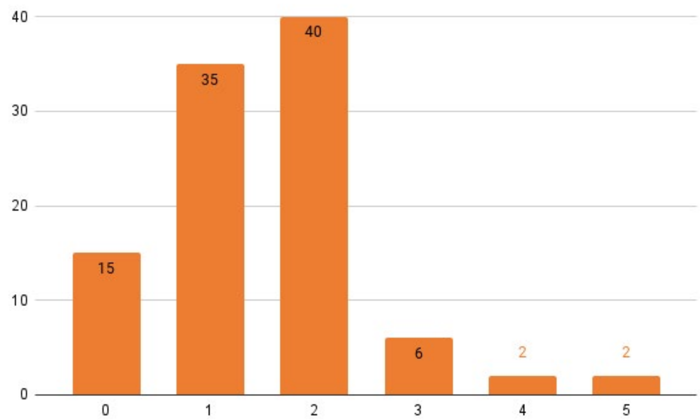


Figure 102 Graph showing the number of balconies of each unit. (Source: Elaboration by the author).

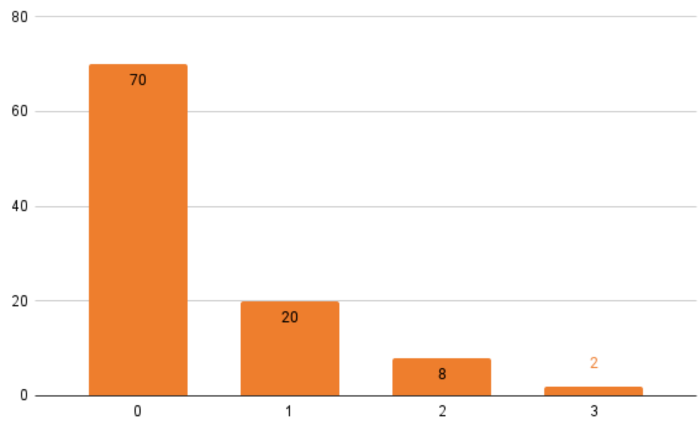


Figure 103 Graph showing the number of terraces of each unit. (Source: Elaboration by the author).

Transforming this variable into a dichotomic one, where 1 stands for the 'presence' of a balcony, and 0 for the 'absence' of it, the result is 85 units with at least one balcony (*Figure 104*).

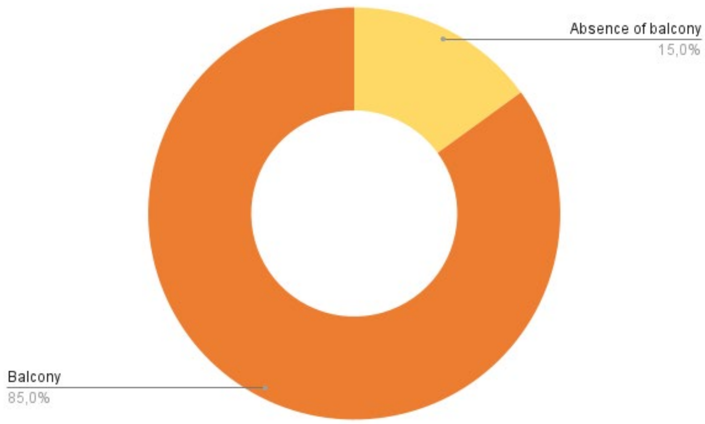


Figure 104 Graph showing the majority of the units with at least one balcony. (Source: Elaboration by the author).

In the case of a dichotomic variable for terraces, only 30 units present at least one terrace, against the other 70 which most likely have at least one balcony (*Figure 105*).

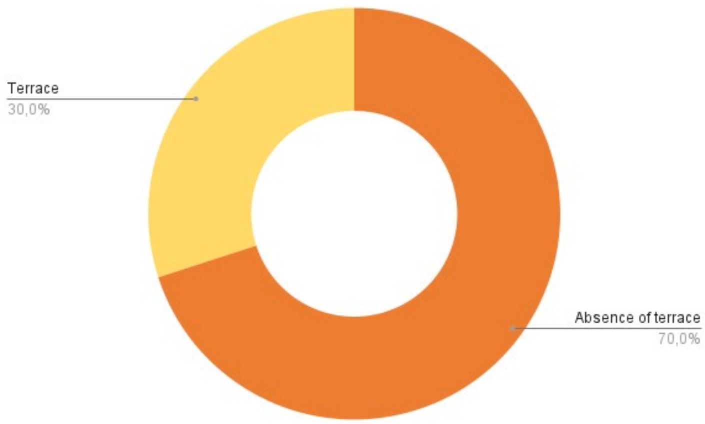


Figure 105 Graph showing the 30 units with at least one terrace. (Source: Elaboration by the author).

Considering the two cases together the value increases, since 97 cases present at least one balcony or terrace (*Figure 106*). It is thanks to the pandemic that buyers have started to consider more the presence of an outdoor space, due to the limits that a new pandemic surge would provoke to the well-being in case of isolation.

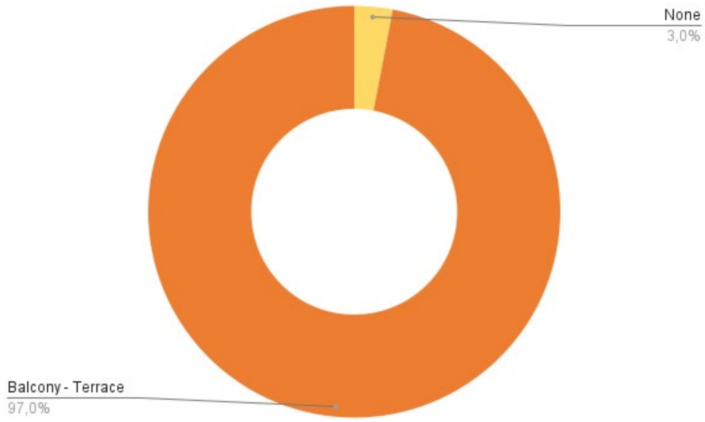


Figure 106 Graph showing the presence of at least one balcony and/or a terrace. (Source: Elaboration by the author).

5.3.5 Daylight

5.3.5.1 Orientation

The orientation of the apartments has been categorized into four levels as a qualitative nominal descriptive variable. In the case of multiple openings, the main façades have been considered. The result is quite balanced between the four levels (*Figure 107*):

1. East to West (20 units);
2. North to South (21 units);
3. Northeast to Southwest (30 units);
4. Northwest to Southeast (29 units).

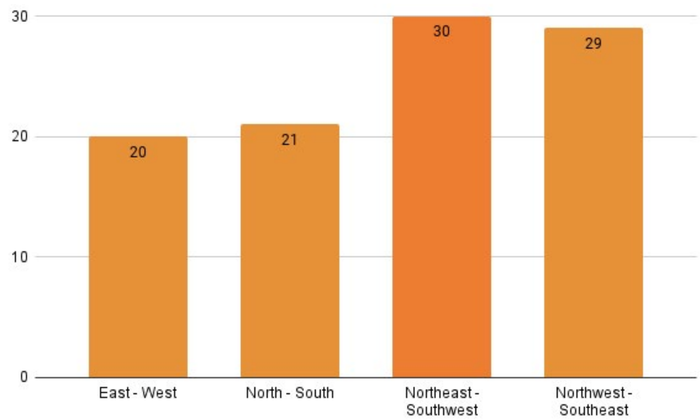


Figure 107 Graph showing the orientation of the units. (Source: Elaboration by the author).

5.3.5.2 Views

It is the number of expositions and from the data collections varies from one to three. It is to be notified that in the data sample no villas or single buildings are being considered, for this reason no 4 views are present. The '1-view' apartments are usually smaller size or mansards and that's the case of 9 apartments. The classic '2-view' apartment is spread in most of the cases, being 72 out of the total. The remaining are 19, and are apartments usually on the side of buildings, which are not attached to others, in most cases the third opening is only the toilet for a functionality matter, otherwise left as a blank façade due to the municipality limits due to the vicinity of other buildings (*Figure 108*).

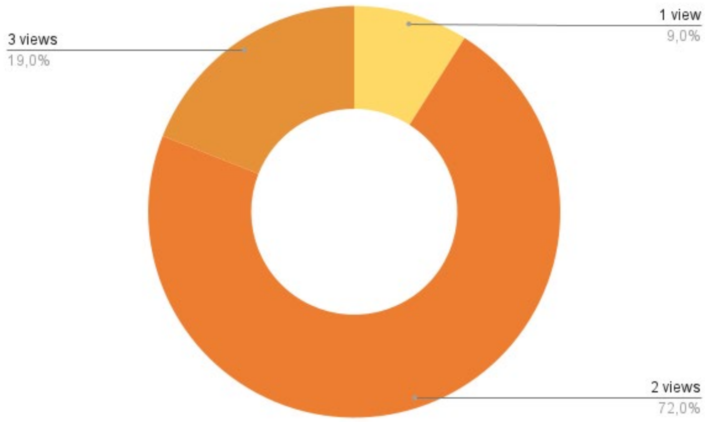


Figure 108 Graph showing the number of views of each unit. (Source: Elaboration by the author).

5.3.5.3 Glazing and Window Frame

The window is an essential element through which natural light can enter. For this reason the type of glass and the type of frame have been included in the data sample. The type of glass, if single or double, has been considered also for the daylighting simulation and further information will be given in *Chapter 6*. The triple glass typology has been excluded because it is not present in any advertisement description and not suitable for the climatic condition of Turin. The window frame has been categorized as in 'wood' (1), 'aluminium' (2) or 'PVC' (3). The information about it has been provided in the advertisement of each unit. In many cases the case of double glass is present in apartments that underwent renovations, while the single glass, present in 43 cases is present in units to be renovated or the ones in good condition but yet to be renewed to comply with the newest regulations (*Figure 109*).

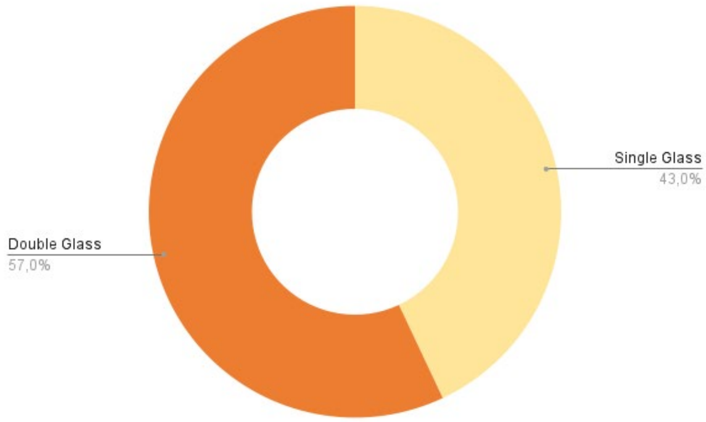


Figure 109 Graph showing the single and double glass in the units. (Source: Elaboration by the author).

The variable of the glass is of qualitative ordinal typology, while the frame typology is of qualitative nominal descriptive. 62 cases present wooden frames, only 7 aluminium and finally 31 PVC (*Figure 110*).

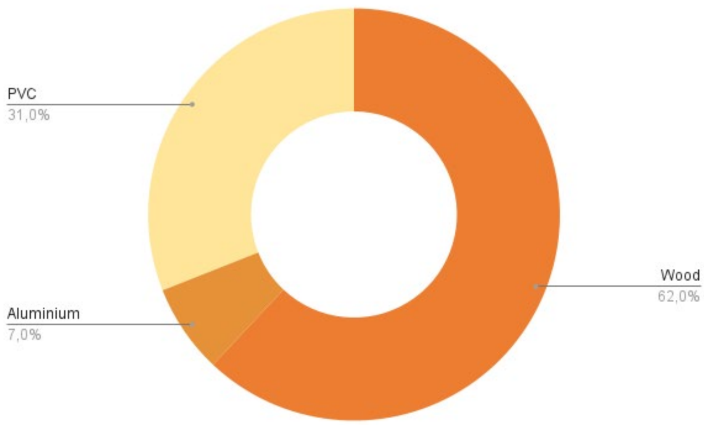


Figure 110 Graph showing materials of the window frame. (Source: Elaboration by the author).

5.3.5.4 WFR: Window-to-Floor Ratio

WFR stands for window-to-floor ratio. According to the regulation the ratio has to be higher than one eight (>1/8). Using a dichotomic variable, where 1 stands for 'comply to the regulations', it is found that only 7 cases do not respect this ratio, most likely due to imprecisions when modeling the apartment due to the limited information provided in the advertisement, since the result expected was to have all the units complying to this regulation (*Figure 111*).

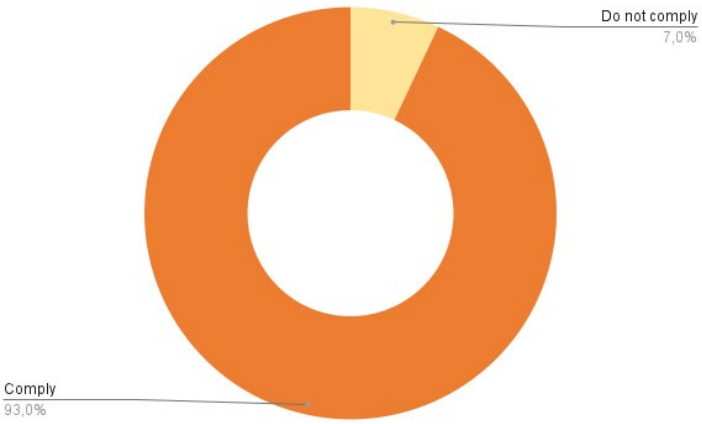


Figure 111 Graph showing the units with the WFR ratio complying to the regulations. (Source: Elaboration by the author).

For a deeper understanding, also the *WFR* considering the whole unit and only the regularly occupied areas have been considered. The threshold has been shifted in three ordinal categories going from 0 to 2:

- '0' when the ratio is below 0.1;
- '1' when it is between 0.1 and 0.15;
- '2' when it is higher than 0.15.

In this way, when considering the whole flat, 56 cases just comply to the minimum, while 37 goes beyond (*Figure 112*).

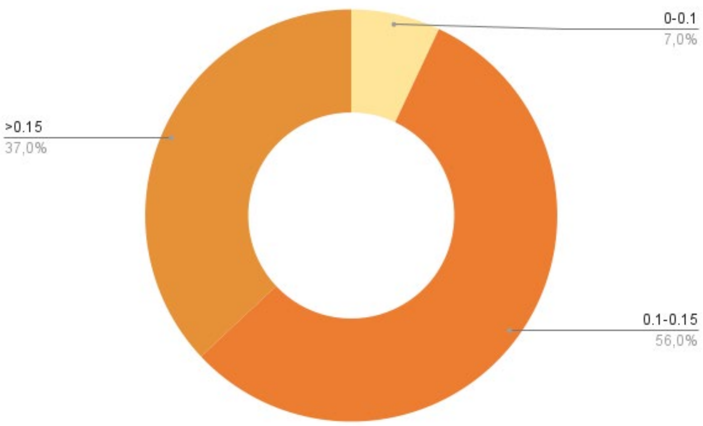


Figure 112 Graph showing the units with the WFR ratio complying to the regulations considering the entire unit size. (Source: Elaboration by the author).

For the regularly occupied spaces only, 23 units respect the minimum requirements, but up to 69 go beyond (*Figure 113*).

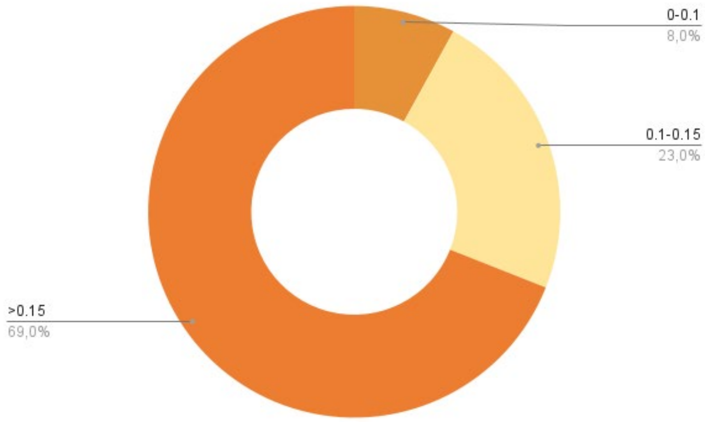


Figure 113 Graph showing the units with the WFR ratio complying to the regulations considering only the regularly occupied areas of the units. (Source: Elaboration by the author).

NOTE: The following variables are the result of the daylighting simulations performed on the units singularly, using the ClimateStudio software as a plugin in Rhinoceros 7, whose process has been explained in the previous Chapter (Chapter 4 - Methodology of the Research), and it will go into further details in the following one. All the variables have been obtained twice, since it has been considered the presence and the absence of vegetation as obstructions.

5.3.5.5 DF: average Daylight Factor DF_m

The Daylight Factor has been measured for both the entire apartment and the regularly occupied areas, excluding bathrooms, halls, and entrances. The ordinal variable is considered in four distinct categories, consistently with the categories set in the standard *EN15193-1:2017*[186]:

1: 'poor' when DF_m <1%;

2: 'average' when 1%< DF_m <2%;

3: 'good' when 2% < DF_m < 3%;

4: 'high' when DF_m > 3%.

The values have been simulated twice in order to consider obstructions, or better the presence of trees, when applicable. Other obstructions such as other buildings have always been considered in all simulations.

The average Daylight Factor has been calculated for the whole flat and all the obstructions spaces from a minimum of 0,16% to a maximum of 2,97%, with an average of 1,08% and a Standard Deviation of 0,48%. Considering the whole flat, 44 units have 'poor' daylighting, 51 'average' and the remaining 5 'good' (*Figure 114*).

[186] CEN (Comité Européen de Normalisation) (2017), *European Standard EN 15193-1:2017, Energy Performance of buildings. Energy requirements for lighting - Part 1: Specifications, Module M9*, Brussels.

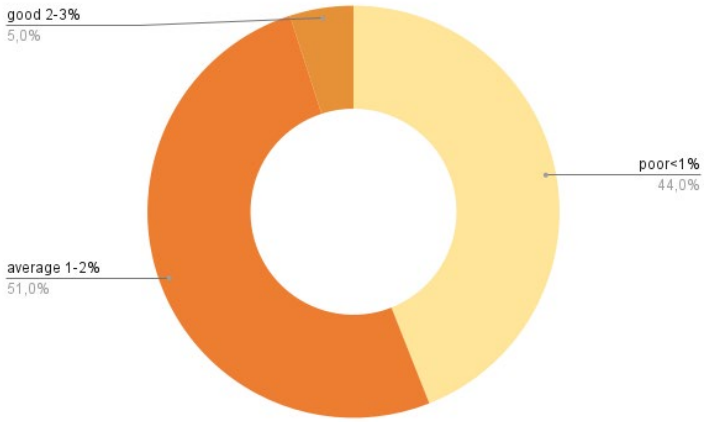


Figure 114 Graph showing DF_m for the whole flat and with all the obstructions. (Source: Elaboration by the author).

If regularly occupied spaces only are considered (such as kitchen, living room, bedroom, studio,...), excluding bathrooms, corridors and other circulation spaces, the results change quite significantly: 35 units have 'poor' daylighting, 60 'average', 4 'good' and the 1 remaining 'high'. The DF_m results vary from a minimum of 0.19% to a maximum of 3.02%, with an average of 1.25% and a Standard Deviation of 0.51% (*Figure 115*).

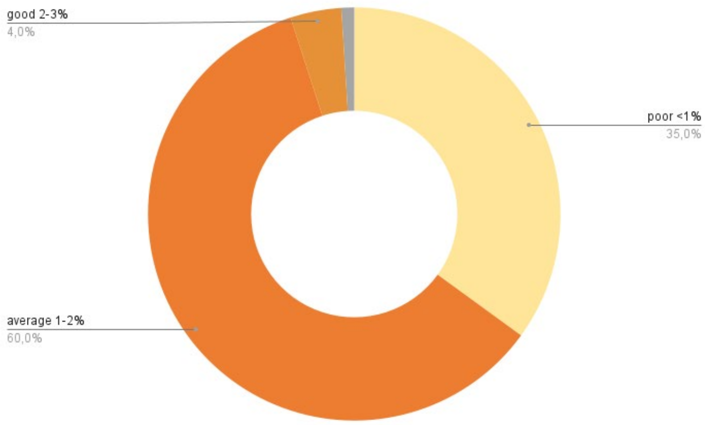


Figure 115 Graph showing DF_m for the regularly occupied areas and with all the obstructions. (Source: Elaboration by the author).

Re-simulating all the variables, this time without the presence of trees, has obtained quite similar values. Considering the whole flat, 35 units have 'poor' daylighting, 58 'average' and 7 'good', with values between 0.16% and 2.97%, with an average of 1.18% and a standard deviation of 0.48 (*Figure 116*).

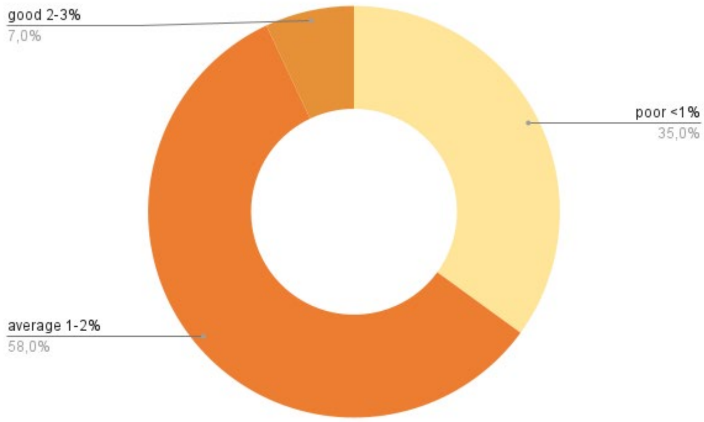


Figure 116 Graph showing DF_m for the whole flat and without considering the presence of trees. (Source: Elaboration by the author).

Following with the regularly occupied spaces simulations without trees, the flats with 'poor' daylighting are 26, 64 the 'average', 9 'good', and only 1 with 'high' daylighting. The values follow the same as with trees, except for the average values with 1.37% and a standard deviation of 0.52 (*Figure 117*).

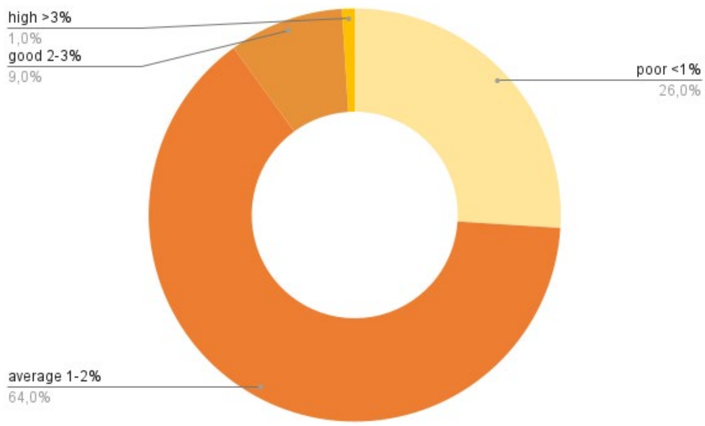


Figure 117 Graph showing the DF_m for the regularly occupied areas and without considering the presence of trees. (Source: Elaboration by the author).

5.3.5.6 sDA: Spatial Daylight Autonomy

$sDA_{300/50\%}$ stands for **Spatial Daylight Autonomy** and it is the percentage of the area with a minimum of 300 lux for 50% of the operating hours per year. The sDA has been reduced to a qualitative ordinal variable with four categories:

1: 'poor' daylighting when sDA <40%;

2: 'average' when between 40% < sDA < 55%;

3: 'good' daylighting when 55% < sDA < 75%;

4: 'high' daylighting when sDA > 75%.

75 of the units have 'poor' daylighting, 19 'average', 5 'good' and only 1 remaining 'high'. The minimum value is 1.86%, with a maximum of 100% and an average of 29.52% with a Standard Deviation of 16.5% (*Figure 118*).

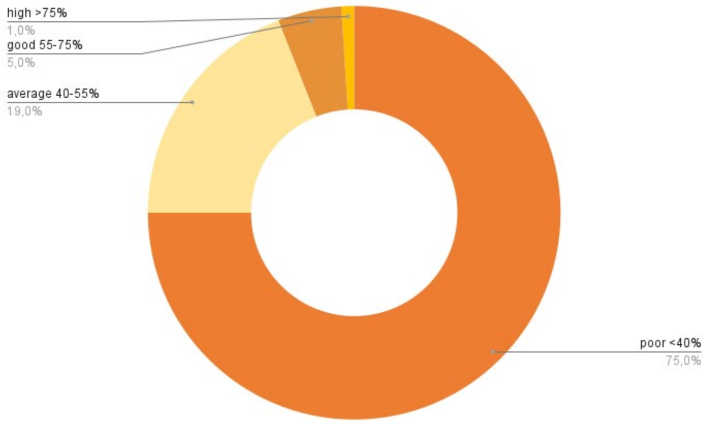


Figure 118 Graph showing the sDA for the regularly occupied areas and considering the presence of trees. (Source: Elaboration by the author).

Removing the trees, the results show 72 cases with 'poor' daylighting, 19 with 'average' daylighting, 7 with 'good' daylighting and 2 with 'high' daylighting. The minimum is again 1.86%, with a maximum of 100% and an average of 33.43% and a standard deviation of 17% (*Figure 119*). sDA resulting in 100% is due to the fact that the 2% of the units receive much more than 300 lux for most of the day, obtaining an accumulation of high observations.

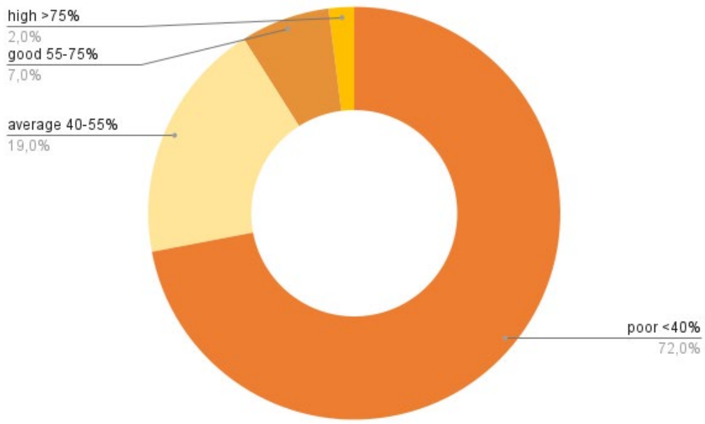


Figure 119 Graph showing the sDA for the regularly occupied areas and without considering the presence of trees. (Source: Elaboration by the author).

5.3.5.7 ASE: Annual Sunlight Exposure

ASE stands for **Annual Sunlight Exposure** and it measures if 1000 lux are observed in a space for at least 250 hours per year due to radiation only (all reflections being excluded). ASE has been considered as a dichotomic variable, whether higher or lower than 10%, which is the threshold value set in the *LEED Protocol*. So, when ASE is higher than 10%, a value of '1' has been assigned, otherwise a value of '0' when ASE > 10%.

Only 17 cases obtained this result, with an average of 5.52% and a maximum value of 20.63%. When removing the trees the cases rise up to 20, with maximum percentages of 35.28% and an average of 6.19%

(*Figure 120*). This is not a satisfying result, and it could be a sign of some errors and imprecisions when designing the single apartments.

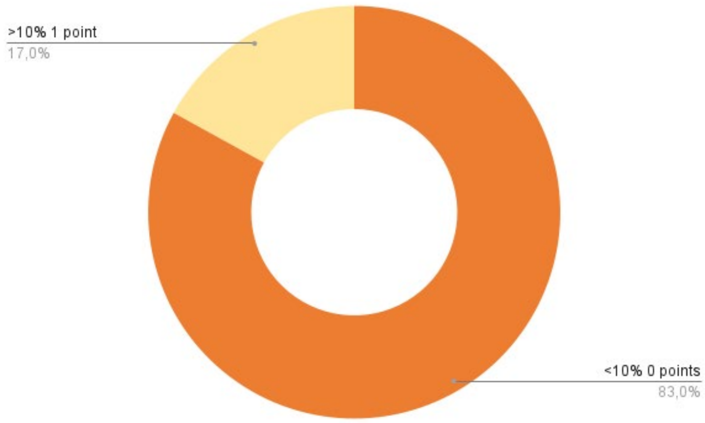


Figure 120 Graph showing the sDA for the regularly occupied areas and without considering the presence of trees. (Source: Elaboration by the author).

5.3.5.8 UDI: Useful Daylight Illuminance

The ordinal qualitative variables describing the Useful Daylight Illuminance (UDI) are 3: UDI.f (fell-short), UDI.a (achieved) and UDI.e (exceeded), and when summing them up 100% is obtained. No official categorization is provided from the regulations so the categories have been assessed according to the results obtained in the following sections.

5.3.5.8.1 Useful Daylight Illuminance fell-short (UDI.f)

It represents the frequency of the occupied time (8 am - 6 pm) when the illuminance value is below 100 lux, meaning very 'low' daylighting is present. The lower the UDI.f and the worse it is in terms of daylighting, since the lower the variable, the lower the illuminance, hence the increase in usage of artificial lighting. It has decided to categorize UDI.f as follows:

1: The 'critical' category goes between 60 and 100%.

2: The 'average' between 30 and 60%.

3: The 'optimal' between 0 and 30%.

The results depict 54 cases in the 'average' and 35 in the 'optimal', with 11 remaining in the 'critical' (*Figure 121*). Disregarding the presence of trees the results improve minimally, with half of the units representing the 'average' category, while 45 of them the 'optimal' (*Figure 122*).

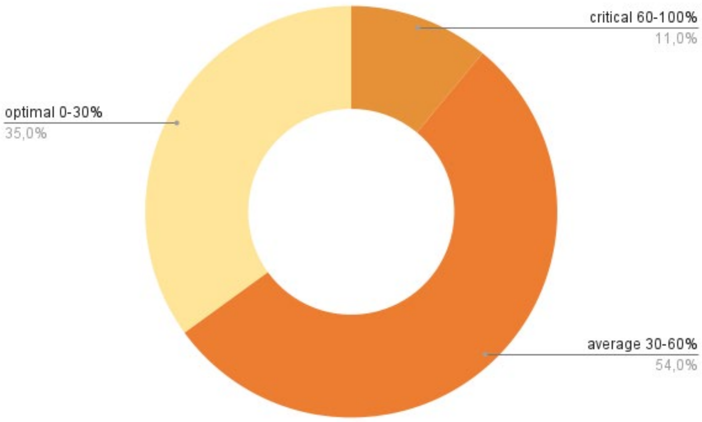


Figure 121 Graph showing the UDI.f results. (Source: Elaboration by the author).

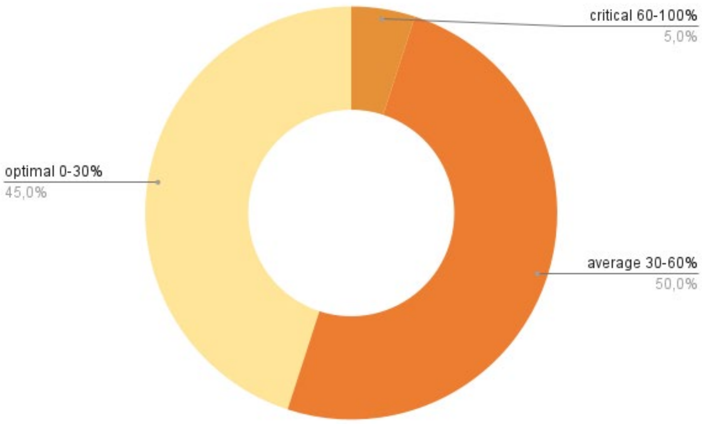


Figure 122 Graph showing the UDI.f results disregarding the presence of trees. (Source: Elaboration by the author).

5.3.5.8.2 Useful Daylight Illuminance achieved (UDI.a)

It represents the frequency of the occupied time (8 am - 6 pm) when illuminance value lies in the comfort range 100 - 3000 lux: accordingly, the higher the value achieved, the better the daylighting. It was decided to categorize UDI.a as follows:

1: The ‘critical' category goes between 0 and 20%.

2: The ‘average' between 20 and 50%.

3: When it is higher than 50% it is the ‘optimal'.

The results depict the majority in the ‘average' category 2 with 75 cases, 18 in the ‘critical' category and the remaining 7 to the ‘optimal' (*Figure 123*). Very similar is in the case without the obstruction of trees, with 79 cases in the ‘average' category, 12 in the ‘critical' category, and the remaining 9 to the ‘optimal' one (*Figure 124*).

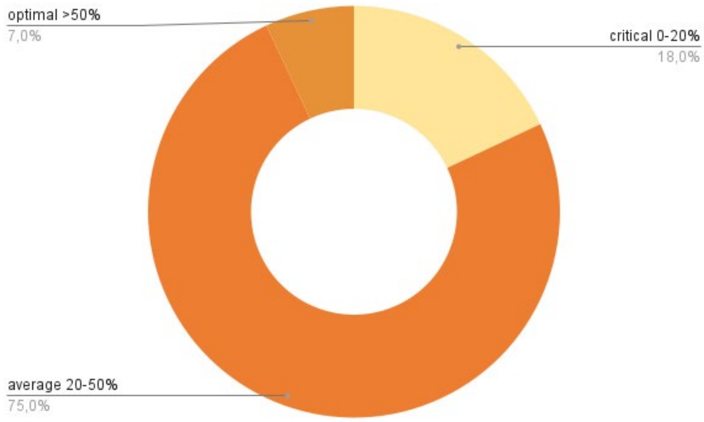


Figure 123 Graph showing the UDI.a results. (Source: Elaboration by the author).

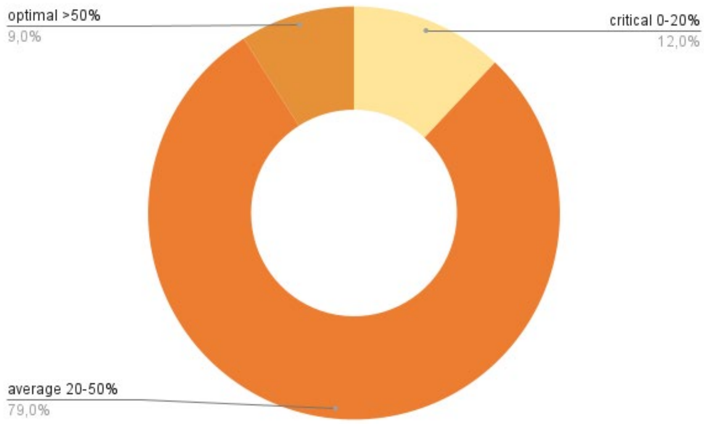


Figure 124 Graph showing the UDI.a results disregarding the presence of trees. (Source: Elaboration by the author).

5.3.5.8.3 Useful Daylight Illuminance exceeded (UDI.e)

It represents the frequency of the occupied time (8 am - 6 pm) when illuminance values are over 3000 lx (exceeded threshold): the higher the value achieved, the higher the potential discomfort in terms of glare or overheating due to solar radiation. The dichotomic variable has been assessed as:

- 0: 'critical' when higher than 75%;
- 1: 'acceptable' if otherwise.

The results show 87 of the units 'acceptable', rising up to 91 when considering the presence of the trees since they create an additional obstruction (*Figure 125*).

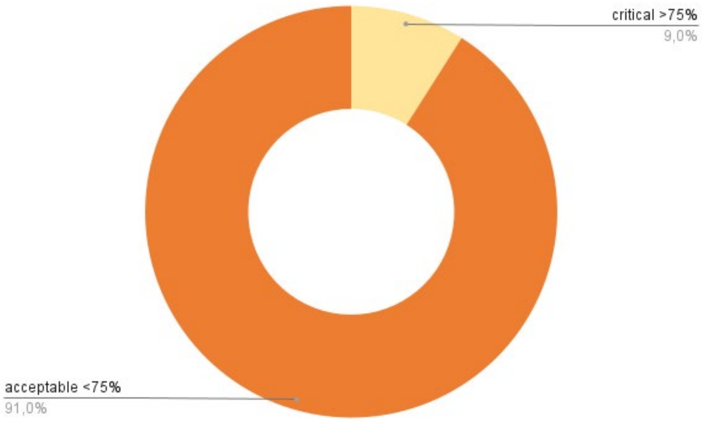


Figure 125 Graph showing the UDI.e results. (Source: Elaboration by the author).

5.3.5.9 Average Illuminance

The average illuminance in lux, provided by the simulations, represents the average illuminance that has been observed in the occupied time (8 am - 6 pm). It has been organized in qualitative ordinal variables into four categories:

- 1: 'critical' when below 200 lux;
- 2: 'acceptable' when between 200 and 400 lux;
- 3: 'high' when between 400 and 500 lux;
- 4: 'very high' when higher than 500 lux.

The results vary from 62 lux up to 555 lux with an average of 254 lux and a standard deviation of 94 lux. The 'critical' units are 29, 40 the 'acceptable' ones and 25 the ones with a 'high' average illuminance, with 6 units even over 500 lux (*Figure 126*).

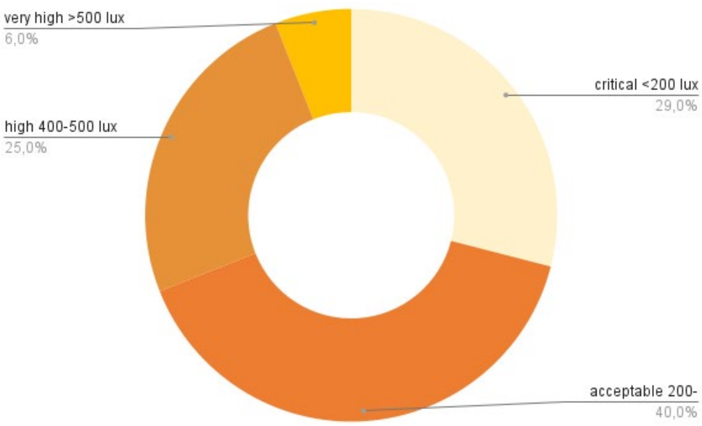


Figure 126 Graph showing the average Lux results. (Source: Elaboration by the author).

Removing the obstacle of the trees the values rise even more, showing values between 62 lux and up to 574 lux with an average of 277 lux and a standard deviation of 93 lux. 11 are the cases over 500 lux, 27 the 'high' values, 42 the 'acceptable' ones and 20 the 'critical' ones (*Figure 127*). Summing up, considering that the minimum request for residential units is 200 lux, this value is reached by 80 units. 300 lux are instead reached only by 38 units.

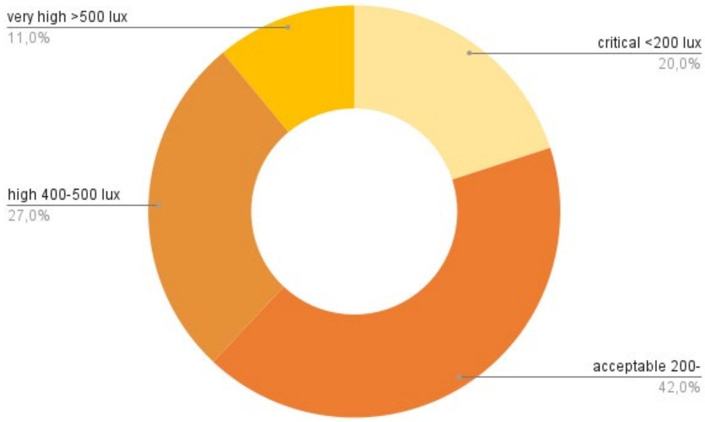


Figure 127 Graph showing the average Lux results with no trees obstruction. (Source: Elaboration by the author).

5.3.5.10 Blinds Closed

The simulation's results provided information about the percentage of blinds open, with which it is possible to obtain the inverted data of the "blind closed" percentage as to avoid glare or thermal discomfort due to overheating. The ordinal variable has been divided into three categories:

1: the most 'excessive use' with percentages above 20%;

2: a 'normal use' of 10-20%;

3: 'minimal or absent use' of <10%.

The results can be considered very positive, since only 3 units use above 20%, the remaining is divided into 44 for a 'normal use' and 53 with a very 'minimal use' (*Figure 128*). The values go from 0% up to 29.6% with an average of 9.68% and a standard deviation of 5.58%.

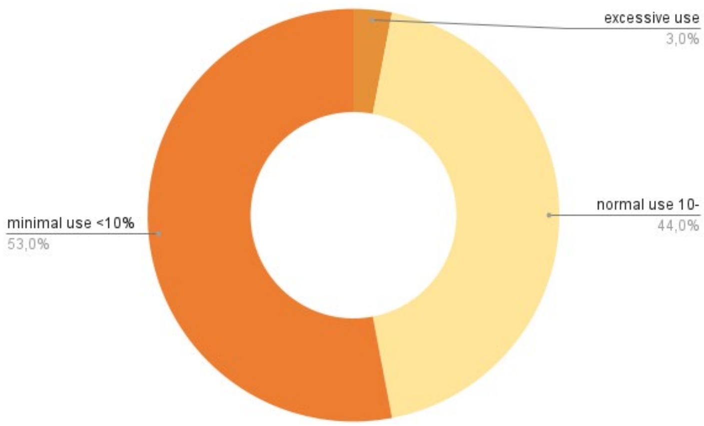


Figure 128 Graph showing the percentage of closed binds. (Source: Elaboration by the author).

Removing the trees, the differences are very minimal, with 5 units above the 20% of blinds usage, 47 for a 'normal use' and finally 48 for a 'minimal use' (*Figure 129*). The minimum and maximum values remain the same, while the average slightly increases up to 10.53% as well as the standard deviation up to 5.84%.

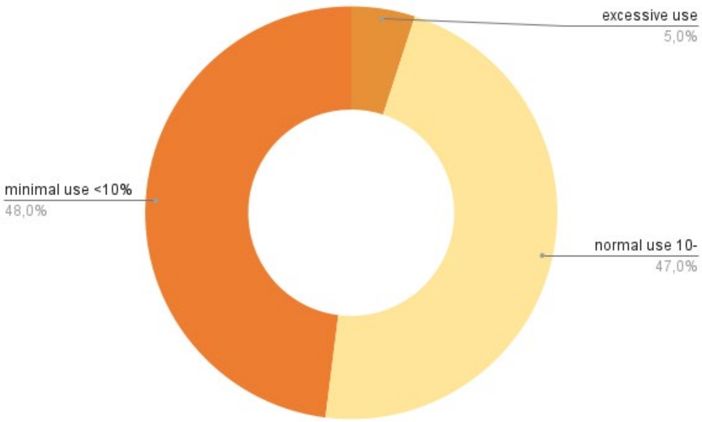


Figure 129 Graph showing the percentage of closed binds with no tree obstruction. (Source: Elaboration by the author).

5.3.5.11 Sky View Factor on Façades

The **Sky View Factor** (**SVF**) is the ratio of the illuminance measured at the center of a façade (at the floor height) to the illuminance of a surface that can 'see' the whole sky dome. It is the measure of the amount of sky 'seen' by the windows of the façades with significant openings, calculating the square meters of each surface and finally weighting all the façades to get a single result for each unit considered. The value obtained is a qualitative ordinal one with three distinct categories:

- 0: VSC in the range 0-15% --> 'critic daylighting';
- 1: VSC in the range 15-27% --> 'average daylighting';
- 2: VSC > 27% --> 'optimal daylighting'.

In all the cases where the only opening present in the façade is a bathroom opening only, it has been considered as blank since it is not part of the regularly occupied spaces, therefore excluded in order to avoid *bias*.

As a result, 63 are in the 'average' category, 30 in the 'optimal' and only 7 in the 'critical' (*Figure 130*). The percentages vary from 9 up to 90% with an average value of 25% and a standard deviation of 11%.

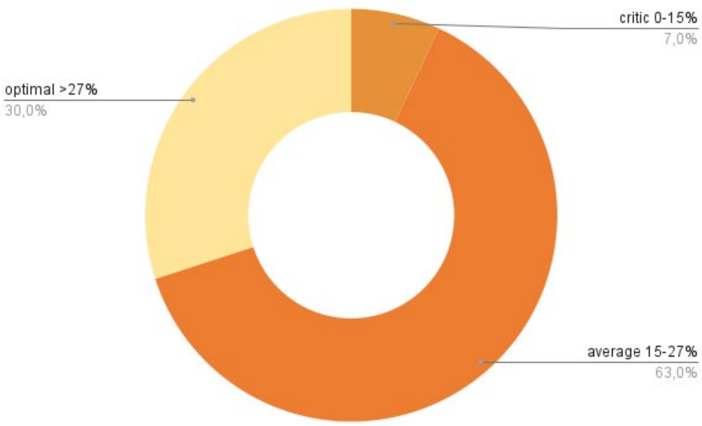


Figure 130 Graph showing the Sky View Factor on the façades. (Source: Elaboration by the author).

Removing trees, the situation slightly differs. 2 are the ones in 'critical' level, 57 in the 'average' and 'optimal' in 41 cases (*Figure 131*). The percentages have seen an average increase to 26.9% and a standard deviation decreasing to 10.65%.

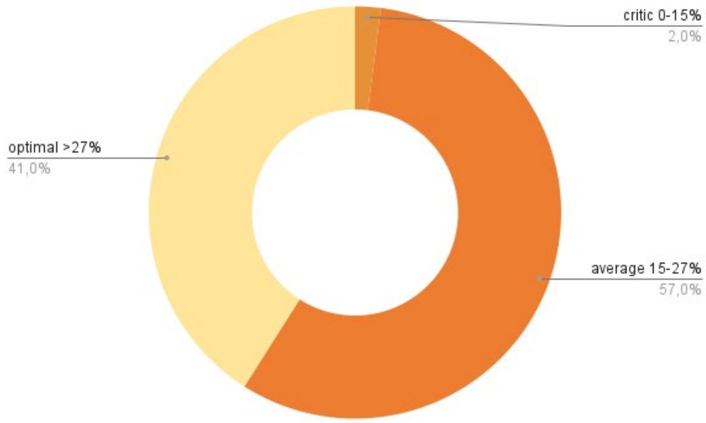


Figure 131 Graph showing the Sky View Factor on the façades with no tree obstruction. (Source: Elaboration by the author).

5.3.6 Energy Efficiency

5.3.6.1 Energy Performance of the Building

The EPBD has categories from A4 to G and has been simplified into three levels. Being all the units considered not new, the best energy classes (A or B) were very limited, only in case of a very recent renovation, while they mostly correspond to the levels between E-F-G. The ordinal variable has been classified in:

- 1: energy classes E-F-G,
- 2: energy classes C-D
- 3: energy classes A(4)-B.

Only 7 are the units in classes from A4 to B, 25 are from class C and D, and all the remaining 68 belong to classes E, F and G (*Figure 132*).

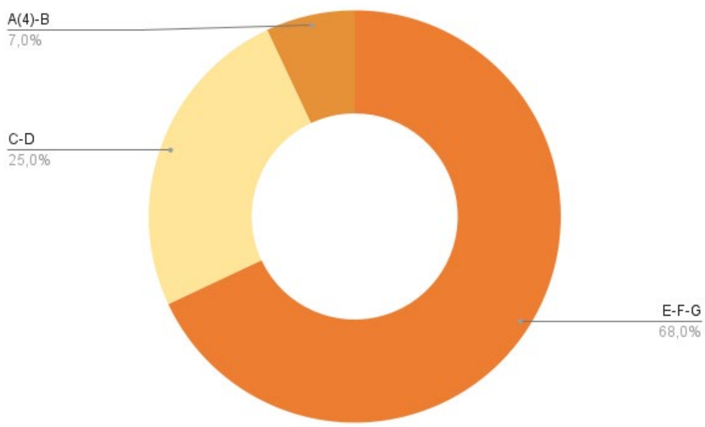


Figure 132 Graph showing the energy performance of the building. (Source: Elaboration by the author).

5.3.6.2 Heating and Cooling

The information about HVAC-systems provided in the unit has been detected from the advertisements.

As **heating** typologies, centralized and autonomous dichotomic categories have been considered (*Figure 133*), followed by the system with ordinal categories with: radiators (1), radiant panels in the floor (2), and air systems (3). This last is a qualitative nominal variable (*Figure 134).* 84 of the units make use of centralized heating (*Figure 133*), with a predominance of radiators in 86 cases, followed by 7 and 3 with flooring and air respectively, the remaining are not being specified (*Figure 134*).

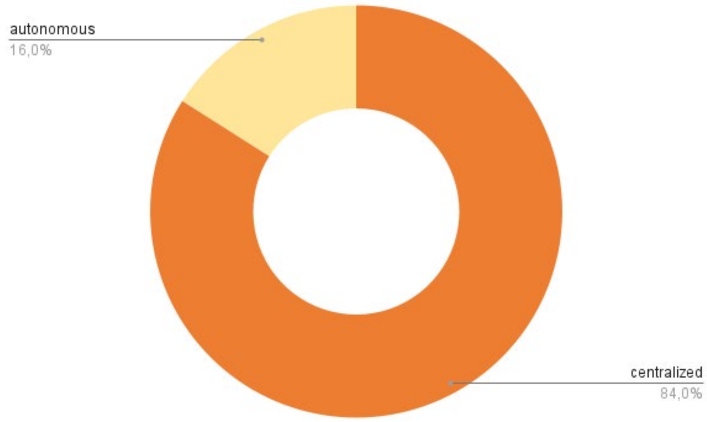


Figure 133 Graph showing the heating typologies. (Source: Elaboration by the author).

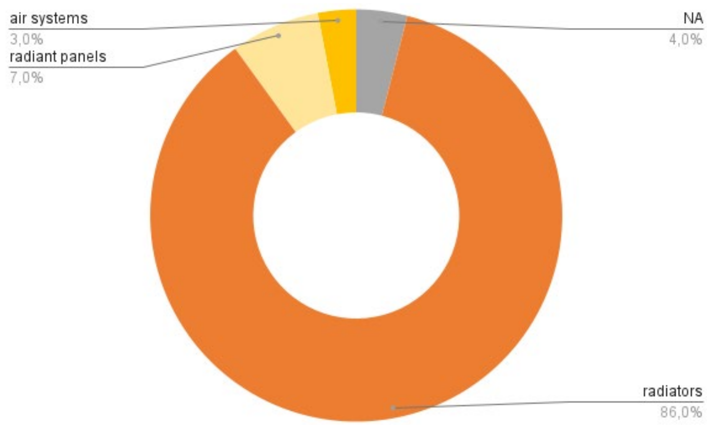


Figure 134 Graph showing the heating typologies. (Source: Elaboration by the author).

Finally, the three sources of heating have been categorized into methane (1), teleheating (2), and gas (3). In 11 cases no information has been provided (0) (*Figure 135*). For the majority, 66 units, methane is the source used, followed by 16 units with teleheating , and 7 units with gas. The variable is qualitative nominal descriptive.

Regarding the cooling system, it has been notified when present with a predisposition using a dichotomic variable and showing as a result only 34 units with its presence or possible disposition (1) (*Figure 136*).

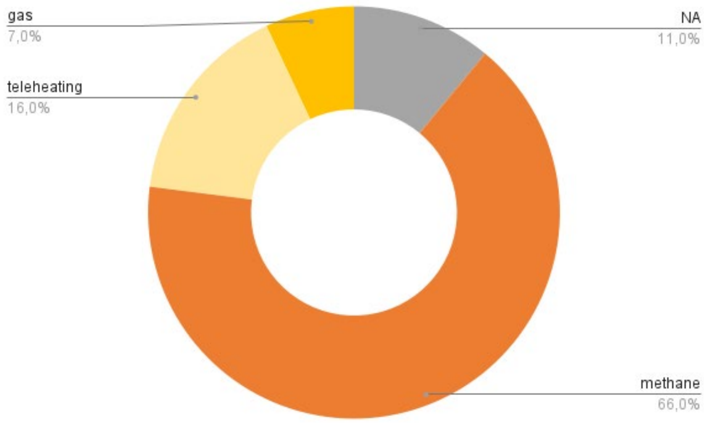


Figure 135 Graph showing the heating sources. (Source: Elaboration by the author).

Figure 136 Graph showing the presence or cooling predisposition. (Source: Elaboration by the author).

5.4 Summary

In this Chapter the data sample and organization has been explained. In *Annex A - Extensive Dataset and Simulation Results*, the Excel spreadsheets with all the information of the data sampling can be found. All the variables have been explained, from the location, to the context, the noise pollution, the indoor configuration, the energy efficiency and all the data found through the daylighting simulations. Only after having properly classified all the variables in numerical values, it is possible to take a further step and start approaching the Multiple Regression analysis models, in order to determine which of these variables listed have the higher influence in the formation of the market prices.

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Chapter 6
Simulations and Multiple Regression Models

6.1 Introduction

Once the data sample has been completed with all the information provided by the Real Estate advertisements, it is time to start modeling the area of *Pozzo Strada* in order to simulate the level of daylighting into the space's units. The simulations are completed, the results are collected and inserted in the data sample as elaborated in the previous chapter. The data sample at this point has all the information needed for the Multiple Regression analysis. The variable correlation determines the correlated variables that cannot coexist in the Multiple Regression model. The outliers, if present and after proper consideration, are removed or substituted with new data. The model is refined until the final result is found.

6.2 3D Modeling

The modeling of the area *Pozzo Strada* has been the primary step to follow the first stage of data sampling. The workflow consisted in dividing the zone D7 *Pozzo Strada* into three separate files, following the sub-segmentation of the area, composed by Rivoli, Monte Cucco-Bardonecchia, and Ruffini. The Geoportale of Turin[187] provides the mapping of the whole city in a *.dwg* format, together with essential information for this study such as the construction year of the building to double check with the advertisements indications, the number of total floors, and the total height of the building.
Once imported the file into **Rhino 7**, the building outlines provided have helped in detecting the buildings' exact location and dimensioning. The

[187] Comune di Torino, *Geoportale*, http://geoportale.comune.torino.it/viscotoga/?printEnabled=true&ricercaTopoEnabled=true&lang=it&topic=CARTOGRAFIA&bgLayer=2&layers=Viario_Viario_Corsi20180507120726829,-Carta_tecnica___fogli_1_1000201912111043053\93.

environment is split into three levels: the base representing the streets (dark gray), the sidewalks defining the perimeter of each block (light gray), and all the buildings with corresponding floor numbers, height, and roof typologies (green) (*Figure 137*). These information have also been double checked via Google Maps. Additionally, trees have been added according to Google Maps views, in particular the ones in the avenues which clearly are part of the obstructions. Due to the dynamicity of the trees over the different seasons and the complexity of modeling them with respect to reality, the simulations have been run twice, once considering them and the other avoiding their presence.

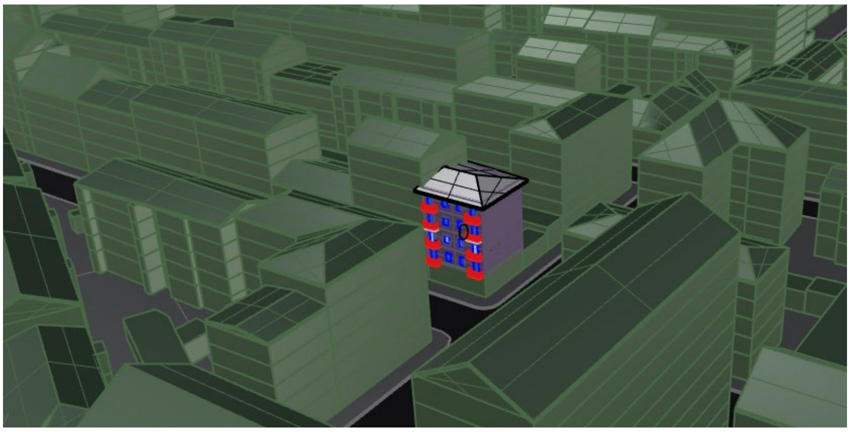


Figure 137 Example of building unit modeled in the context. (Source: Elaboration by the author).

When the setting is ready, the single unit modeling starts. To begin, the photos collected from the Real Estate advertisements found online are organized and, with the help of the pictures of the interiors, the floor plans provided have been the base for starting modeling. Each of the units has been singularly modeled in **Revit** for a fast result.

The floor plans provided are mostly with no measure indications, and for this reason, the results are clearly subjected to errors. Thanks to the city outline provided by Geoportale, the units are scaled in accordance with the building perimeter. The 3D models are simple and represent the walls' thickness and height, the internal doors, as well as the openings towards the outside, and the balconies or terraces, with handrails.

The model have been imported into **Rhino 7**. The units have been then splitted in all the different levels: walls, roofs, ceilings, floors, door and window frames, and windows. The glazing of the windows is represented by a single surface directed towards the outside, in order for it to be able to reflect the light during the simulations. The units have been then positioned in the correct location and floor and the other levels are copied. In case the balconies/terraces' rhythm differs on each floor, it is adjusted to reality, in order to represent obstructions in the best possible way.

For preparing the unit for the simulations, each room has been provided with a plane directed upwards, and all the relevant façades (with openings) are in a second moment covered by a plane directed towards the outside. Next, the simulation settings are set up.

6.3 Simulations: Settings and Results

6.3.1 Simulations Setting

The simulations are carried out with the Software **ClimateStudio** by Solemma, which is a plug-in in Rhino 7. The simulations, as said above, have been carried out twice, for considering the presence of vegetation as an obstruction and to compare the values' variance when disregarding their presence.

At first, a specific material, with a corresponding ideal reflectance value (%), has been assigned to each layer. The materials have been idealized as constant in all the housing units in order to have a real comprehension of daylighting under the same material conditions (*Figures 138-139-140-141*).

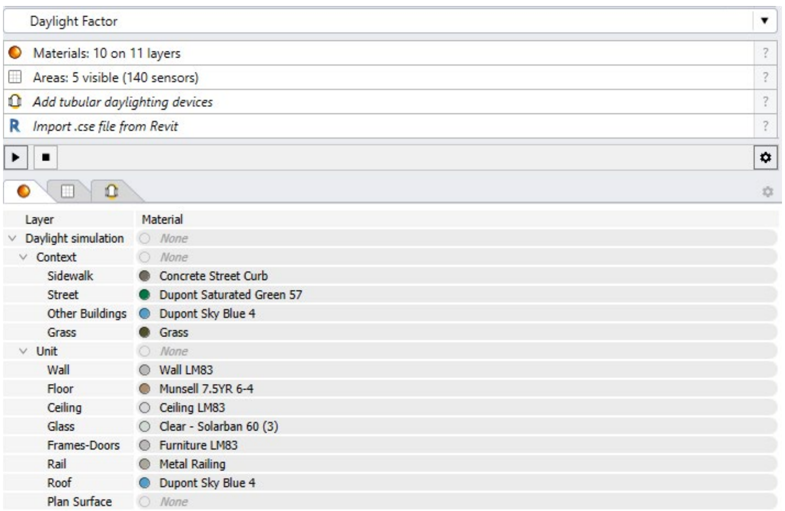


Figure 138 Materials are assigned to each corresponding layer. (Source: Elaboration by the author from ClimateStudio).

Context Materials	Name in Default Library	Reflectance (%)
Sidewalk	Concrete Street Curb	15,34
Street	Dupont Saturated Green 57	12,27
Other Buildings	Dupont Sky Blue 4	29,88
Grass	Grass	7,38

Unit Materials	Name in Default Library	Reflectance (%)
Wall	Wall LM83	50,00
Floor	Munsell 7.5YR 6-4	29,99
Ceiling	Ceiling LM83	70,00
Railing	Metal Railing	39,80
Roof	Dupont SKy Blue 4	29,88
Windows and Doors Frames	Furniture L83	50,00

Glass Typology	Name in Default Library	U-value (W/m²K)	SHGC	T_{VIS}	Embodied Energy (MJ/m²)	Embodied Carbon ($kgCO_2/m^2$)
Single Glazing	Clear	5,820	0,818	0,877	217,500	13,195
Double glazing	Clear - Solarban 60 (3)	1,660	0,460	0,696	432,600	74,962

Figure 139-140-141 Tables reporting data for each material selected from the Default Library in ClimateStudio. (Source: Re-elaborated by the author from ClimateStudio Default Library.)

The only variable changing is the type of glass, depending on the information provided by the advertisements. Two types of glazing typologies have been found:

- single glazing: for this type of glass a U-value of 5,82 W/m²K and a visible transmittance of 0,877 (87,7%) have been assumed (*Figure 142*);
- double pane glazing: for this technology a U-value of 1,66 W/m²K and a visible transmittance of 0,696 (70%) have been assumed (*Figure 143*).

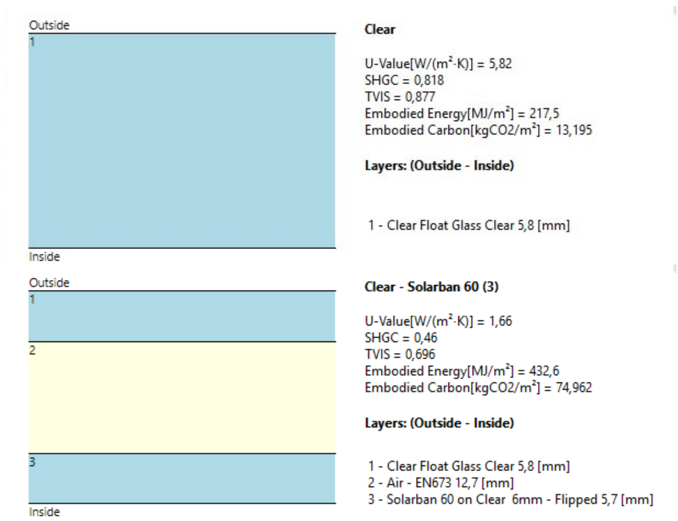


Figure 142-143 Single and double glass information. (Source: Glazing typology chosen from Climate Studio Default Library).

Once the materials have been assigned, the individual room surfaces are selected and the software calculates the surfaces' areas automatically (*Figure 144*). The planes of each room are set on the height of a working plane, at 75 cm from the floor level.

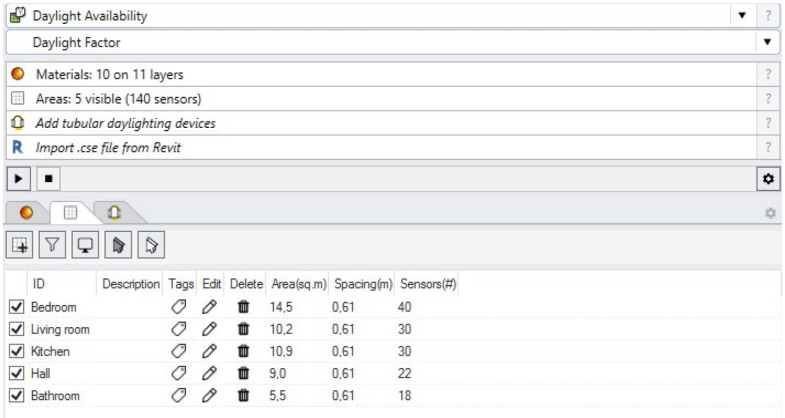


Figure 144 The rooms are added in order to be processed in the simulations. (Source: Elaboration by the author from ClimateStudio).

The blinds have been inserted selecting all the glazed surfaces of the unit under study, in order to define, through the calculation, the percentage of usage. The blinds have always been assigned no matter their presence in each of the interior spaces of the units, as to guarantee once again the same conditions for all the sample (*Figure 145*).

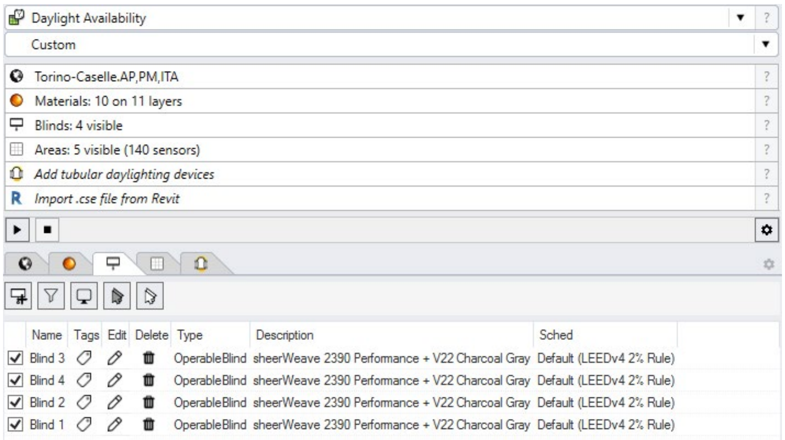


Figure 145 Blinds setting for each glazed area. (Source: Elaboration by the author from ClimateStudio).

Finally, as the last preparatory setting, the ambient bounces are set to 6 and the samples per pass to 64 (*Figure 146*).

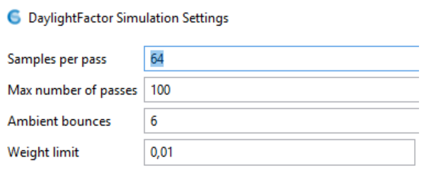


Figure 146 Daylight Simulation Setting. (Source: Elaboration by the author from ClimateStudio).

6.3.2 Simulations running

Once all the settings have been set, the simulations can finally start and they have taken place in three stages:

1. Daylight Availability - **Daylight Factor** (in relation to the rooms of the unit);
2. Daylighting Availability - climate-based daylight metrics: **sDA, ASE, UDI, average illuminance, blinds open** (in relation to the rooms of the unit);
3. Daylight Availability - **Sky View Factor** (in relation to the significant façades of the unit, one by one): this has been calculated through the average Daylight Factor value of each façade of the unit.

1. The Daylight Factor calculated on the floor plan can be directly executed after all the settings listed above. The results are quickly obtained both in terms of data and visually. In *Figure 157* the Daylight Factor in the gridded points is available and the result is synthesized by room and by total unit in *Figure 148*. The total mean and average Daylight Factor percentages have been reported on the Excel Spreadsheet, as well as the Average Daylight Factor per room, in order to calculate the regularly occupied spaces's Daylight Factor only.

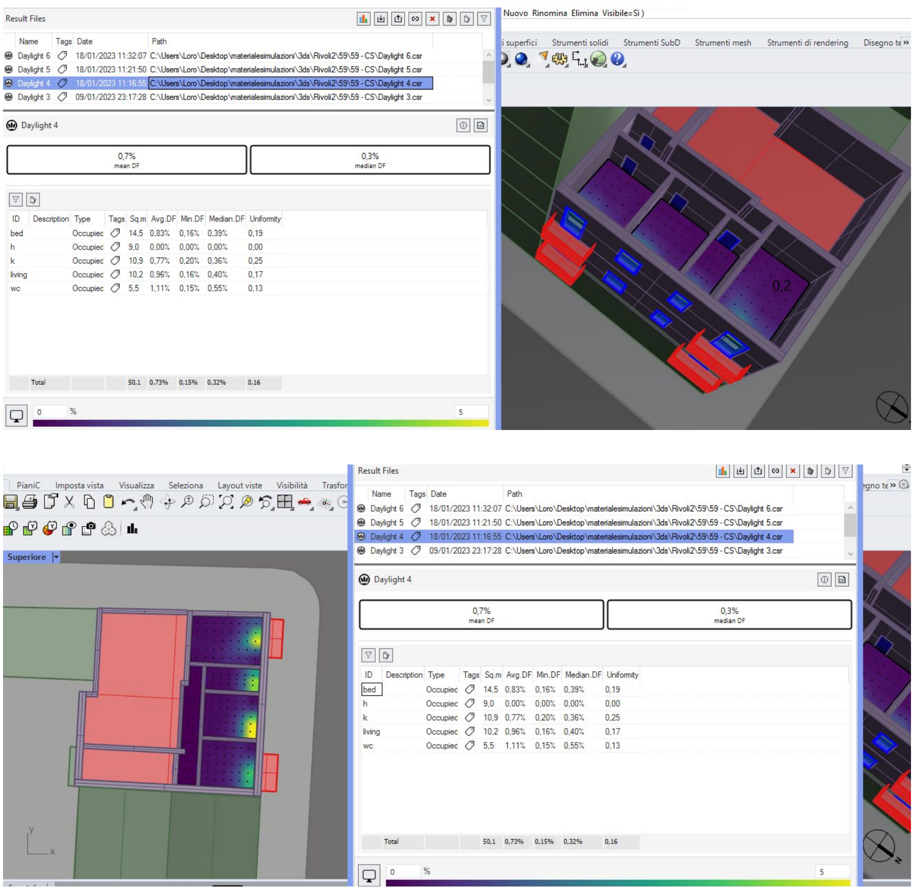


Figure 147-148 Daylight Factor simulations results. (Source: Elaboration by the author from ClimateStudio).

2. For the simulations of Custom Daylight Availability, it has been necessary to take further action. The location is a piece of essential information to be provided, in this case Turin. In this simulation also the blinds setting will be used and the results obtained are for: the average Useful Daylight Illuminance UDIa - UDIe - UDIf (%) (*Figure 149*), the spatial Daylight Autonomy $sDA_{300/50\%}$ (%) (*Figure 150*), the Annual Sunlight Exposure $ASE_{1000,250h}$ (%) (*Figure 151*), the average illuminance (lux) (*Figure 152*), and the blinds open (%) (*Figures 153-154*). All these new data found represent results that would differ depending on the setting, since they are all climate-based simulations. Information about a specific day and time can be obtained easily from the simulations, but for the aim of this study, the annual results are to be considered enough.

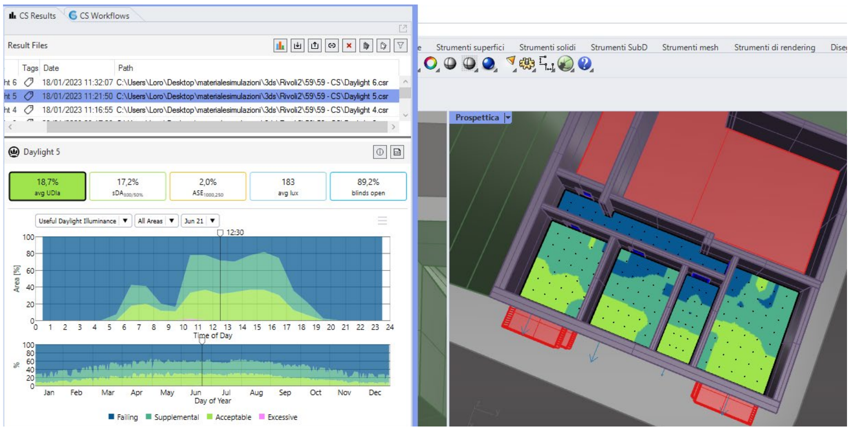


Figure 149 Average Useful daylight Illuminance achieved UDIa (%) example results. (Source: Elaboration by the author from ClimateStudio).

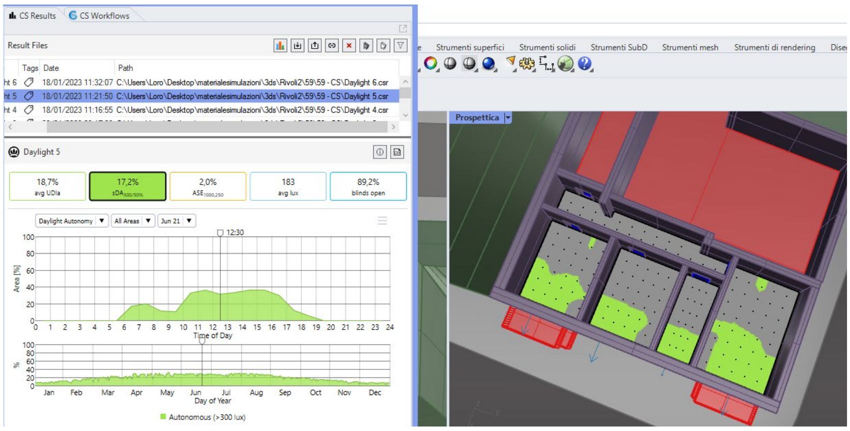


Figure 150 The spatial Daylight Autonomy sDA300/50% (%) example results. (Source: Elaboration by the author from ClimateStudio).

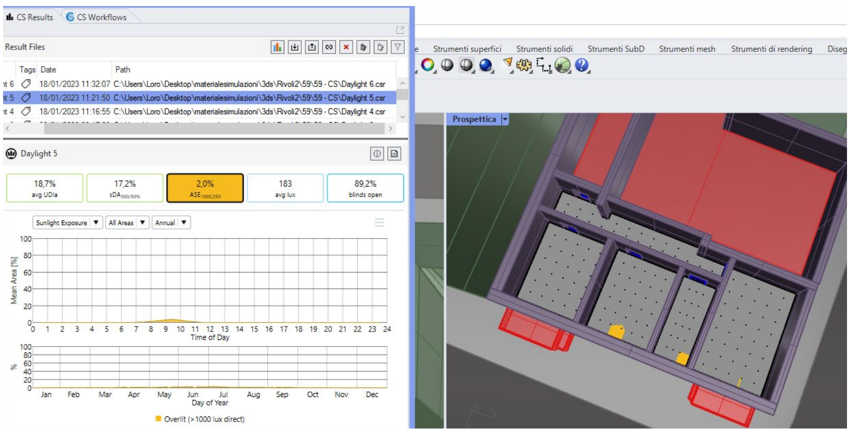


Figure 151 Annual Sunlight Exposure ASE1000,250 (%) example results. (Source: Elaboration by the author from ClimateStudio).

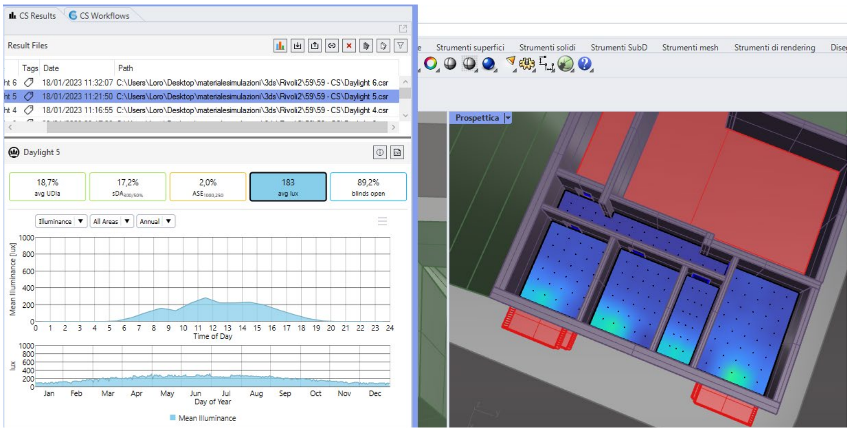
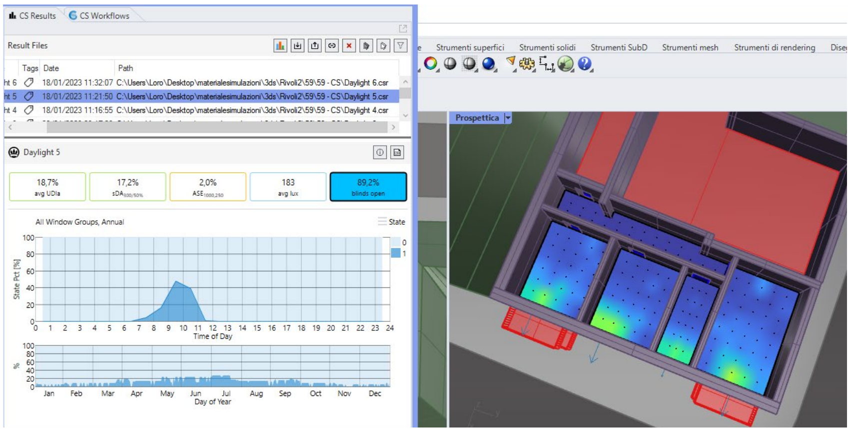


Figure 152 Average lux example results. (Source: Elaboration by the author from ClimateStudio).



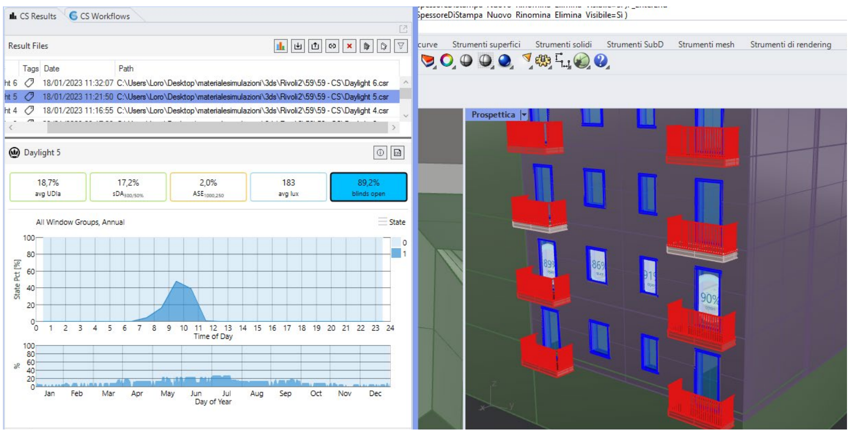


Figure 153-154 Blinds open (%) example results. (Source: Elaboration by the author from ClimateStudio).

3. The third simulation to develop is the Daylight Factor in all the significant façades for the calculator of the Sky View Factor (SVF) of the unit. A façade is to be considered significant when openings are present in regards to regularly occupied spaces, meaning that in the case of a bathroom opening or distribution opening alone it would not be considered. The result obtained is to be defined as **Sky View Factor** (%). The results are once again determined by the gridded points and the total result is given as shown in *Figures 155-156*.

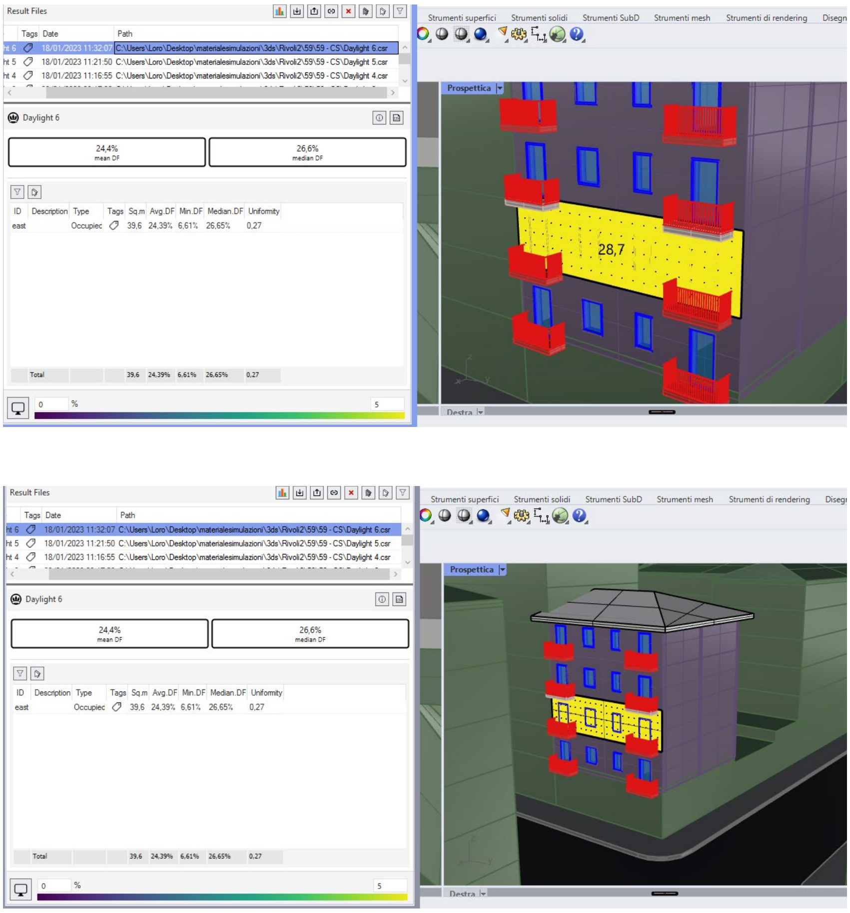


Figure 155-156 Sky View factor SVF (%) example result for one façade. (Source: Elaboration by the author from ClimateStudio).

6.3.3 Simulations Results

While obtaining results from each simulation, the data have been reported on an Excel Spreadsheet to keep track of each of the units, and only later added in the data sample according to the categories and levels explained in the previous Chapter.

As an example, the data for unit 1 has been reported extensively here. The room's dimensioning and glazing areas of each space have been identified for defining the **window to floor ratio** (WFR) (RAI in Italian), which should always be guaranteed to be higher than 1/8. It is to be considered once again the presence of errors since no floor plan dimensions have been completely available, also the windows height and width have been approximated during the 3D modeling because no information is provided in the advertisements. Other information reported are the **average Daylight Factor** (%) of the entire apartment and of the regularly occupied areas only, followed by the spatial Daylight Autonomy, the Annual Sunlight Exposure and the Useful Daylight Illuminance for the regularly occupied areas only (*Figure 157*). The average illuminance (lux) in the total apartment, as well as the blinds usage have been reported directly in categories. The "*blinds open*" data has been inverted in order to determine the actual usage of blinds when they are closed because of glare, heat gain or excessive sunlight exposure. The Sky View Factor of the total unit has been determined by calculating the weighted average of all the façades and each of their respective Sky View Factor (%).

IDAP	Room	Surfacefloor	Surfacewindow	Surface/8	>0.125	WFR
1	*Bedroom1*	13	1,66	1,625	SI	0,13
	Bathroom	3,2	0,31	0,4	NO	0,1
	Bedroom2	12,2	0,89	1,525	NO	0,7
	Hall	6,1	0	0,7625		0
	Kitchen-living	9,9	1,66	1,2375	SI	0,17
Tot	**Habitable Spaces**	**35,1**	**4,21**	**4,3875**	**SI**	**0,1199430199**
Tot		**44,4**	**4,52**	**5,55**	**SI**	**0,1**

IDAP	Room	DFmflat	DFmh	sDAh	ASEh	UDI.f	UDI.a	UDI.e
1	*Bedroom1*	0,79	0,79	14,29	5,71	39,64	23,81	0,1
	Bathroom	0,12		0	0	98,32	0	0
	Bedroom2	0,76	0,76	11,43	5,71	55,76	17,87	0,1
	Hall	0		0	0	100	0	0
	Kitchen-living	1,15	1,15	19,23	0	25,94	24,94	0
Tot		**0,71**	**0,89**	**14,69**	**4,1**	**41,38**	**22,07**	**0,07**

vegetation presence

IDAP	Room	DFmflat*	DFmh*	sDAh*	ASEh*	UDI.f*	UDI.a*	UDI.e*
1	*Bedroom1*	0,79	0,79	17,14	5,71	42,87	23,27	0,12
	Bathroom	0,15		0	0	97,99	0	0
	Bedroom2	0,79	0,79	11,43	5,71	56,44	18,18	0,16
	Hall	0		0	0	100	0	0
	Kitchen-living	1,16	1,16	23,08	0	25,18	24,48	0
Tot		**0,72**	**0,9**	**16,83**	**4,1**	**42,6**	**21,84**	**0,1**

Figure 157 Collection of the results for one unit given by the software Rhino 7 and the plug-in ClimateStudio. (Source: Elaboration by the author).

6.4 Preparation of Multiple Regression Models

6.4.1 Spearman Correlation

Having the data sample complete means the Multiple Regression analysis can finally start. The variable correlation is carried out. The software used for this second stage of the study is ***Gretl***[188].

The data are all collected in numerical quantitative variables in the Excel Spreadsheet, each defined by their categories and levels and with an identification name. For the correct execution in the software, no text variable can be included, but only numerical values, and also no spaces between words are allowed.

The variables' correlation is an important step for identifying the relation between two variables and their possible correlation. This step is very important because it determines the variables that cannot coexist in the same model because they are related to each other, and with which the result would be biased. From the Spearman correlation each relation between variables is assigned a value between -1 to 1, where 1 is a total negative linear correlation, 0 an absence of correlation, and +1 a correlation. The closer the value is to 1, the higher the correlation between the two variables is.

A clear example of correlated variables is the listing price and the price per m^2. In the correlation it is highlighted the slightly correlated variables and the highly correlated ones in different colors. *Figure 158* is the results given by the software Gretl, later re-elaborated by the author in the following *Figures 159-160-161-162*.

The list of strongly correlated variables (>0,75) follows here (*Figures 159-160-161-162* in orange):

- *Listing Price* (PRICE) and *Surface* (SURFACE);
- The *View-out* (VIEW_OUT) and the *Floor Number* (FLOOR_NUMBER) of the unit;
- The *number of rooms* (n_ROOMS) and both the *Listing Price* (PRICE) and the

[188] Baiocchi G., Distaso W., (2003), *GRETL: Econometric software for the GNU generation*, JSTOR.

Surface (SURFACE);
- The *number of bathrooms* (BATHROOMS) and the *Surface* (SURFACE);
- The (sDA) *spatial Daylight Autonomy* (SDAh) and the *median Daylight Factor* (medianDF);
- The *Useful Daylight Illuminance achieved* (UDIa) and the *Useful Daylight Illuminance fell-short* (UDIf);
- The *average illuminance* (avg_lux) and both the *total average Daylight Factor* (DFmflat) and the *average Daylight Factor of the regularly occupied spaces* (DFmh) .

Some of the other variables that are correlated (>0,50) to each other are (*Figures 159-160-161-162* in light orange):
- The *Price per m²* (PRICESQM) and the *Listing Price* (PRICE);
- The *Listing Price* (PRICE) and the *number of bathrooms* (BATHROOMS);
- The *number of rooms* (n_ROOMS) and the *number of bathrooms* (BATHROOMS);
- The *Useful Daylight Illuminance achieved* (UDIa) and the *average Daylight Factor of the regularly occupied spaces* (DFmh);
- The *Useful Daylight Illuminance achieved* (UDIa) and the *Useful Daylight Illuminance fell-short* (UDIf);
- The *average illuminance* (considering the presence of the vegetation as obstruction) (avg_lux*) and the *average Daylight Factor of the regularly occupied spaces* (DFmh*), the *spatial Daylight Autonomy* (sDAh*), the *Useful Daylight Illuminance fell-short* (UDIf*) and the *Useful Daylight Illuminance achieved* (UDIa*);
- the *spatial Daylight Autonomy* (sDAh) with the *median Daylight Factor* (medianDF);
- the *Useful Daylight Illuminance achieved* (UDIa) and the *spatial Daylight Autonomy* (sDAh);
- the *average illuminance* (avg_lux) and the *total average Daylight Factor* (DFmflat), the *spatial Daylight Autonomy* (sDAh), and the *Useful Daylight Illuminance achieved* (UDIa).

Many other variables are correlated because the origin is the same, such as the different set of data obtained by the simulations with or without the presence of vegetation, as well as the variables that have been repeated changing their categories. During the models analysis, for example, it has been investigated the importance of the floor of the unit in relation to daylight, so one variable describes whether the unit is in the last floor (1 'yes', 0 'no'), another describes whether it is a 'low' (1), 'intermediate' (2), or 'high floor' (3). In these cases, when inserting the variables into the model, the choice of one automatically excluded the other.

```
Coefficienti di correlazione, usando le osservazioni 1 - 100
Valore critico al 5% (per due code) = 0,1966 per n = 100

        ZONE123 BUILDING_TYPOL~ FACADE_TYPOLOGY           PRICE
         1,0000          0,1662          0,0593          0,1168 ZONE123
                         1,0000         -0,0295          0,2173 BUILDING_TYPOL~
                                         1,0000          0,3445 FACADE_TYPOLOGY
                                                         1,0000 PRICE

        SURFACE        PRICESQM    FLOOR_NUMBER     TOTAL_FLOOR
         0,1162          0,0261          0,2292          0,1901 ZONE123
         0,1719          0,1760          0,2670          0,5289 BUILDING_TYPOL~
         0,2166          0,3986          0,2678          0,3522 FACADE_TYPOLOGY
         0,8647          0,6130          0,3545          0,5383 PRICE
         1,0000          0,1815          0,3323          0,5197 SURFACE
                         1,0000          0,1742          0,2879 PRICESQM
                                         1,0000          0,5624 FLOOR_NUMBER
                                                         1,0000 TOTAL_FLOOR

     LAST_FLOOR          FLOORS CONSTRUCTION_Y~        CATEGORY
        -0,0585          0,0715          0,2787          0,2334 ZONE123
        -0,0796          0,0829          0,2875          0,1350 BUILDING_TYPOL~
        -0,0224         -0,0128          0,3035          0,3420 FACADE_TYPOLOGY
        -0,1214          0,0163          0,3074          0,3727 PRICE
        -0,0733          0,0597          0,1439          0,3894 SURFACE
        -0,1549         -0,0907          0,4515          0,2049 PRICESQM
         0,3949          0,5535          0,1283          0,1752 FLOOR_NUMBER
        -0,1401          0,0328          0,4224          0,3440 TOTAL_FLOOR
         1,0000          0,8214         -0,1654         -0,1037 LAST_FLOOR
                         1,0000         -0,0427         -0,0166 FLOORS
                                         1,0000          0,3816 CONSTRUCTION_Y~
                                                         1,0000 CATEGORY

   CONSERVATION        ELEVATOR           GREEN        VIEW_OUT
        -0,0088          0,0785          0,1602          0,2274 ZONE123
        -0,1368          0,5130          0,0202          0,2273 BUILDING_TYPOL~
         0,1226          0,3566          0,4177          0,1926 FACADE_TYPOLOGY
         0,0419          0,4616          0,2812          0,2669 PRICE
        -0,1938          0,3155          0,2705          0,2490 SURFACE
         0,3443          0,5745          0,1803          0,1543 PRICESQM
        -0,0875          0,2524          0,2434          0,7798 FLOOR_NUMBER
        -0,2059          0,5944          0,3394          0,4233 TOTAL_FLOOR
         0,0162         -0,2212         -0,0950          0,3338 LAST_FLOOR
        -0,0764         -0,1190          0,0483          0,5236 FLOORS
         0,0591          0,4960          0,1950          0,1453 CONSTRUCTION_Y~
        -0,0644          0,2528          0,3225          0,1279 CATEGORY
         1,0000         -0,0869         -0,0759         -0,0857 CONSERVATION
                         1,0000          0,2264          0,2535 ELEVATOR
```

Figure 158 Spearman Variables Correlation. (Source: Elaboration by the author from Gretl).

	IDAP	ZONE123	BUILDING_TYPOLOGY	FACADE_TYPOLOGY	PRICE	SURFACE	PRICESQM	FLOOR_NUMBER	TOTAL_FLOOR	LAST_FLOOR	CONSTRUCTION_YEAR	CATEGORY	CONSERVATION	ELEVATOR	GREEN	VIEW_OUT	NOISE_average	n_ROOMS	BATHROOMS	KITCHEN	
IDAP	1	-0,027	0,2125	0,096	0,0369	0,083	-0,0433	0,0663	0,1442	-0,0658	0,0765	0,0342	-0,0244	0,0812	0,0673	0,1178	-0,1513	0,0268	0,0545	0,0345	IDAP
ZONE123		1	0,1662	0,0593	0,1168	0,1162	0,0261	0,2292	0,1901	-0,0585	0,2787	0,2334	-0,0088	0,0785	0,1602	0,2274	0,0081	0,0661	0,0629	0,0244	ZONE123
BUILDING_TYPOLOGY			1	-0,0295	0,2173	0,1719	0,176	0,267	0,5289	-0,0796	0,2875	0,135	-0,1368	0,513	0,0202	0,2273	-0,369	0,1106	0,1276	-0,0222	BUILDING_TYPOLOGY
FACADE_TYPOLOGY				1	0,3445	0,2166	0,3986	0,2678	0,3522	-0,0224	0,3035	0,342	0,1226	0,3566	0,4177	0,1926	0,1153	0,1844	0,156	0,0506	FACADE_TYPOLOGY
PRICE					1	0,8647	0,613	0,3545	0,5383	-0,1214	0,3074	0,3727	0,0419	0,4616	0,2812	0,2669	-0,0265	0,8219	0,7207	0,3126	PRICE
SURFACE						1	0,1815	0,3323	0,5197	-0,0733	0,1439	0,3894	-0,1938	0,3155	0,2705	0,249	-0,01	0,9205	0,8003	0,3515	SURFACE
PRICESQM							1	0,1742	0,2879	-0,1549	0,4515	0,2049	0,3443	0,5745	0,1803	0,1543	-0,0129	0,1845	0,1851	0,0372	PRICESQM
FLOOR_NUMBER								1	0,5624	0,3949	0,1283	0,1752	-0,0875	0,2524	0,2434	0,7798	-0,0714	0,2863	0,2517	0,0486	FLOOR_NUMBER
TOTAL_FLOOR									1	-0,1401	0,4224	0,344	-0,2059	0,5944	0,3394	0,4233	-0,2405	0,4156	0,398	0,1154	TOTAL_FLOOR
LAST_FLOOR										1	-0,1654	-0,1037	0,0162	-0,2212	-0,095	0,3338	0,1218	-0,0463	0,0212	0,0192	LAST_FLOOR
CONSTRUCTION_YEAR											1	0,3816	0,0591	0,496	0,195	0,1453	0,0009	0,0912	0,16	-0,0251	CONSTRUCTION_YEAR
CATEGORY												1	-0,0644	0,2528	0,3225	0,1279	0,0017	0,3106	0,3328	0,1039	CATEGORY
CONSERVATION													1	-0,0869	-0,0759	-0,0857	0,0597	-0,1537	-0,1459	-0,0028	CONSERVATION
ELEVATOR														1	0,2264	0,2535	-0,1141	0,2289	0,2787	-0,0679	ELEVATOR
GREEN															1	0,3017	0,0279	0,127	0,2457	0,0275	GREEN
VIEW_OUT																1	-0,0594	0,2174	0,2237	0,1142	VIEW_OUT
NOISE_average																	1	-0,0322	0,1079	-0,1427	NOISE_average
n_ROOMS																		1	0,7274	0,4391	n_ROOMS
BATHROOMS																			1	0,2468	BATHROOMS
KITCHEN																				1	KITCHEN

	BALCONIES	TERRACES	ORIENTATION	VIEWS	GLAZING	FRAME	WFR	WFRallflat	DFmflat	DFmh	medianDF	SDAh	ASEh	UDIf	UDIa	
IDAP	-0,0469	0,0948	0,1333	0,1713	0,0486	0,0742	0,0319	0,1031	0,275	0,2819	0,1296	0,1517	0,0466	0,2507	0,1887	IDAP
ZONE123	-0,1119	0,1422	0,4474	0,065	-0,031	-0,1004	0,0092	-0,0044	0,1086	0,0764	-0,081	-0,0355	0,0491	0,0664	0,0443	ZONE123
BUILDING_TYPOLOGY	0,0366	0,1717	0,2046	0,0569	-0,0731	-0,1253	0,0972	0,0346	0,1147	0,125	0,0948	0,08	0,1339	0,1478	0,1968	BUILDING_TYPOLOGY
FACADE_TYPOLOGY	-0,0163	-0,021	0,0344	0,2154	-0,0353	-0,1976	0,086	0,1135	0,1024	0,0632	-0,0222	0,0408	0,0012	0,0508	0,0028	FACADE_TYPOLOGY
PRICE	0,0159	0,3656	0,2036	0,5375	-0,0916	-0,1987	0,0767	0,0012	0,1252	0,1351	-0,0047	0,1163	-0,0011	0,0697	0,0759	PRICE
SURFACE	-0,0157	0,4242	0,1821	0,5852	-0,1301	-0,1692	0,0189	-0,0285	0,1701	0,1519	0,0637	0,1699	-0,1171	0,1213	0,103	SURFACE
PRICESQM	0,0124	0,1086	0,0501	0,1599	0,0368	-0,1776	0,068	0,0255	-0,0077	0,0347	-0,0432	0,009	0,1521	0,0098	0,0031	PRICESQM
FLOOR_NUMBER	0,1848	0,1048	0,2539	0,2325	0,1223	0,0633	0,105	0,1575	0,4365	0,4636	0,3574	0,3651	0,2601	0,4044	0,4199	FLOOR_NUMBER
TOTAL_FLOOR	-0,0197	0,2475	0,418	0,3342	-0,1027	-0,1604	0,1576	0,1916	0,1402	0,2028	0,1198	0,2092	0,0501	0,1403	0,1155	TOTAL_FLOOR
LAST_FLOOR	0,2168	-0,1175	-0,1051	0,0481	0,0303	0,1971	-0,0588	0	0,3355	0,3316	0,3495	0,3092	0,3062	0,2443	0,3156	LAST_FLOOR
CONSTRUCTION_YEAR	-0,2646	0,2528	0,2618	0,2424	-0,0198	-0,2381	0,2628	0,1226	-0,0265	0,0798	-0,0263	-0,0108	0,0552	0,1075	0,041	CONSTRUCTION_YEAR
CATEGORY	-0,195	0,2152	0,2458	0,3006	0,0113	-0,0826	0,0258	-0,0124	0,0752	0,0494	-0,1215	-0,0604	-0,024	0,11	0,0786	CATEGORY
CONSERVATION	-0,0771	-0,1312	-0,0509	-0,1029	0,2353	0,2524	0,0197	0,0027	-0,0315	-0,0945	-0,0769	-0,1466	0,0168	-0,1512	-0,0583	CONSERVATION
ELEVATOR	-0,021	0,164	0,0771	0,1403	0,0137	-0,1876	0,0755	0,0616	0,0439	0,123	0,0743	0,1169	0,0735	0,0952	0,069	ELEVATOR
GREEN	-0,1111	0,2252	0,1713	0,1869	-0,0162	-0,2187	0,1142	0,1356	0,191	0,1744	0,016	0,1759	-0,0438	0,3275	0,2585	GREEN
VIEW_OUT	0,1808	0,1244	0,1821	0,1285	0,1219	-0,0005	0,1512	0,2967	0,473	0,4338	0,3327	0,3798	0,3054	0,4708	0,4026	VIEW_OUT
NOISE_average	-0,2119	0,0212	-0,1666	-0,0201	0,0871	0,0602	-0,1691	-0,1412	0,0311	0,013	-0,0486	-0,128	-0,1908	-0,045	-0,1362	NOISE_average
n_ROOMS	0,0479	0,4029	0,1438	0,5967	-0,1355	-0,1343	0,0635	-0,0078	0,1075	0,0669	0,0067	0,1205	-0,1047	0,1021	0,1022	n_ROOMS
BATHROOMS	-0,0687	0,3006	0,1351	0,4988	-0,0412	-0,0772	-0,0866	-0,0862	0,1067	0,1127	0,0569	0,1051	-0,0995	0,0764	0,0644	BATHROOMS
KITCHEN	0,0429	0,1282	0,1377	0,321	-0,1785	-0,2702	0,0834	0,068	0,0979	0,0544	0,0262	0,0824	-0,0464	0,0447	0,0762	KITCHEN
BALCONIES	1	-0,5232	-0,1322	0,1688	0,0384	0,0411	0,2151	0,2282	0,032	0,1138	0,1547	0,1713	-0,0176	0,0739	0,1623	BALCONIES
TERRACES		1	0,1571	0,2606	0,0575	-0,1056	0,1051	0,0794	0,0566	-0,0193	-0,0652	0,0576	-0,0787	0,1943	0,0192	TERRACES
ORIENTATION			1	0,0739	-0,1617	-0,1393	-0,0086	0,1019	0,1497	0,151	0,0138	0,0333	-0,0379	-0,0046	0,0392	ORIENTATION
VIEWS				1	0,0894	-0,0822	0,2037	0,0651	0,0298	0,0949	0,1065	0,2443	-0,2408	0,2002	0,1579	VIEWS
GLAZING					1	0,5899	0,0784	0,0307	0,008	0,0182	-0,0747	-0,1065	-0,0371	0,0739	-0,0421	GLAZING
FRAME						1	0,0356	0,1536	-0,0205	-0,0371	0,1088	0,052	0,1245	-0,0097	-0,0422	FRAME
WFR							1	0,6029	0,0182	0,0646	-0,0263	0,0791	0,0198	0,2892	0,2548	WFR
WFRallflat								1	0,3111	0,2788	0,2806	0,4511	0,1755	0,4477	0,3734	WFRallflat
DFmflat									1	0,8392	0,4153	0,5174	0,3494	0,5793	0,6417	DFmflat
DFmh										1	0,5046	0,5611	0,3137	0,5886	0,6665	DFmh
medianDF											1	0,7811	0,1651	0,3838	0,5166	medianDF
SDAh												1	0,3708	0,5469	0,6492	SDAh
ASEh													1	0,1645	0,3142	ASEh
UDIf														1	0,8	UDIf
UDIa															1	UDIa

Figures 159-160 Spearman Variables Correlation. (Source: Elaboration by the author from Gretl).

	UDIe	avg_lux200	avg_lux300	avg_lux	blindsclosed	SF%	DFmflat*	DFmh*	medianDF*	sDAh*	ASEh*	UDIf*	UDIa*	UDIe*	avg_lux200*	
IDAP	0,0744	0,2191	0,1195	0,167	-0,0498	0,1953	-0,021	0,1717	0,0629	0,093	0,0251	0,3072	0,1233	-0,0438	0,1143	IDAP
ZONE123	-0,1062	0,0746	0,0298	0,0455	-0,1867	-0,0235	0,0418	0,1093	-0,0472	-0,0527	0,039	0,1649	0,1172	-0,1306	0,1559	ZONE123
BUILDING_TYPOLOGY	-0,093	0,0898	0,1983	0,1563	-0,1839	0,0804	0,0812	0,077	0,1105	0,099	0,1479	0,242	0,2673	-0,1144	0,1365	BUILDING_TYPOLOGY
FACADE_TYPOLOGY	0,036	0,0422	0,1191	0,0428	0,0402	-0,0326	0,0193	0,048	0,0741	0,0933	-0,0448	0,0921	0,043	0,0413	0,0671	FACADE_TYPOLOGY
PRICE	-0,0201	0,059	0,1192	0,064	0,0382	-0,0331	0,0474	0,2038	0,1433	0,2071	-0,0704	0,1228	0,1785	-0,0086	0,0696	PRICE
SURFACE	0,0534	0,0568	0,1313	0,0665	0,064	-0,0447	0,0795	0,2335	0,1409	0,2215	-0,1709	0,1566	0,211	0,0542	0,0961	SURFACE
PRICESQM	-0,0785	0,019	0,1185	0,0655	-0,042	-0,019	0,0317	0,0201	0,1012	0,1009	0,074	0,0196	0,0351	-0,0293	-0,0048	PRICESQM
FLOOR_NUMBER	-0,0722	0,3461	0,2842	0,3358	-0,268	0,2712	0,2231	0,4815	0,401	0,3831	0,2584	0,4669	0,487	-0,1273	0,3967	FLOOR_NUMBER
TOTAL_FLOOR	-0,0461	0,0703	0,2157	0,1222	-0,103	-0,0515	0,0754	0,2882	0,2047	0,2576	0,0722	0,3466	0,3027	-0,0539	0,2463	TOTAL_FLOOR
LAST_FLOOR	-0,1048	0,2358	0,1514	0,2672	-0,0898	0,2397	0,2548	0,2474	0,2802	0,1842	0,25	0,1286	0,1907	-0,1041	0,1875	LAST_FLOOR
CONSTRUCTION_YEAR	-0,1116	0,0142	0,1125	0,0307	-0,0343	-0,091	-0,0633	0,0451	0,1175	0,0218	0,0254	0,1658	0,0969	-0,0405	0,0064	CONSTRUCTION_YEAR
CATEGORY	0,0418	-0,0251	0,1103	0,0172	-0,1315	-0,0013	-0,0737	0,0664	-0,0352	-0,01	-0,0732	0,1088	0,1377	0,1401	0,0427	CATEGORY
CONSERVATION	0,1115	-0,0153	-0,0781	-0,1039	0,0727	0,0406	-0,0832	-0,1349	-0,0268	-0,1348	-0,0243	-0,2834	-0,1945	0,0621	-0,1377	CONSERVATION
ELEVATOR	-0,0564	0,0134	0,2015	0,1018	-0,0935	0,0065	0,1285	0,0988	0,1056	0,1483	0,039	0,1428	0,1705	-0,0263	0,0911	ELEVATOR
GREEN	0,0782	0,1756	0,2492	0,1987	-0,0379	0,0067	-0,1969	0,2472	0,0135	0,2016	-0,095	0,3403	0,3127	0,0264	0,2533	GREEN
VIEW_OUT	-0,1106	0,3477	0,2951	0,3615	-0,2886	0,2705	0,188	0,5179	0,355	0,4162	0,272	0,5639	0,5568	-0,1808	0,4388	VIEW_OUT
NOISE_average	0,0754	-0,0552	-0,0813	-0,0965	0,1562	-0,1013	0,0327	-0,0459	-0,0019	-0,1489	-0,2262	-0,191	-0,2051	0,1386	-0,1218	NOISE_average
n_ROOMS	0,0728	0,0397	0,045	0,021	0,0582	-0,0288	0,0453	0,1336	0,0864	0,1607	-0,1388	0,127	0,1552	0,0619	0,0463	n_ROOMS
BATHROOMS	0,1128	0,0893	0,0147	0,0184	0,1526	0,0211	0,0033	0,1822	0,1179	0,1529	-0,1381	0,102	0,1095	0,0404	0,0319	BATHROOMS
KITCHEN	0,0717	0,097	-0,0468	0,0144	0,1033	0,0071	0,0669	0,0617	0,0655	0,0823	-0,0767	0,0592	0,1758	0,0279	0,1486	KITCHEN
BALCONIES	0,0203	0,0068	-0,0812	0,0551	0,0442	0,1797	0,0166	0,0918	0,1804	0,1691	-0,0296	0,0946	0,1541	-0,0987	0,1035	BALCONIES
TERRACES	0,0377	-0,0166	0,2086	0,0729	0	-0,1634	0,0032	0,0068	-0,0693	0,0317	-0,1175	0,1706	0,0978	0,1011	0,0484	TERRACES
ORIENTATION	-0,0281	0,0737	0,0775	0,0889	-0,0656	0,0383	-0,0272	0,214	0,0117	-0,0197	0,0548	0,1379	0,1144	-0,0859	0,1736	ORIENTATION
VIEWS	0,0605	0,0083	-0,0042	-0,0175	0,2074	-0,0103	-0,0528	0,0159	0,1849	0,2209	-0,3368	0,231	0,124	0,0744	-0,0481	VIEWS
GLAZING	0,2209	-0,0762	-0,1166	-0,1047	-0,0907	0,3189	0,0008	-0,115	-0,0528	-0,1211	-0,0202	0,0069	-0,1002	0,2048	-0,1313	GLAZING
FRAME	0,1611	-0,092	-0,0092	-0,0438	-0,0098	0,2748	0,0073	-0,084	0,0976	0,0014	0,115	-0,0676	-0,1742	0,1293	-0,1424	FRAME
WFR	0,0507	0,1479	0,0144	0,0695	0,0352	0,0425	-0,232	0,0614	-0,0021	0,0961	0,0392	0,3226	0,3748	0,0105	0,2548	WFR
WFRallflat	-0,1358	0,2392	0,4276	0,4151	-0,0911	0,0931	0,0596	0,3485	0,3068	0,4623	0,2113	0,5218	0,4825	-0,2061	0,3381	WFRallflat
DFmflat	-0,3312	0,7199	0,6357	0,7847	-0,448	0,4573	0,5212	0,7137	0,4343	0,5171	0,3355	0,4898	0,5836	-0,4128	0,5247	DFmflat
DFmh	-0,3333	0,6459	0,5511	0,7215	-0,3512	0,443	0,4685	0,8036	0,5019	0,5617	0,2891	0,5132	0,5746	-0,4434	0,4761	DFmh
medianDF	-0,1028	0,2198	0,4779	0,5007	-0,0262	0,2312	0,3687	0,4636	0,813	0,6897	0,1311	0,3296	0,4325	-0,2226	0,1602	medianDF
SDAh	-0,2911	0,3572	0,7065	0,6742	-0,1169	0,1919	0,3036	0,4778	0,6741	0,8884	0,3092	0,48	0,5669	-0,3794	0,2604	SDAh
ASEh	-0,5088	0,2534	0,5025	0,4431	-0,4542	0,2879	0,2932	0,2876	0,1861	0,3535	0,9051	0,1461	0,2672	-0,4583	0,2263	ASEh
UDIf	-0,1014	0,6313	0,4963	0,6467	-0,2831	0,3494	0,0816	0,4317	0,3635	0,5058	0,1261	0,7678	0,671	-0,135	0,5045	UDIf
UDIa	-0,2184	0,6874	0,5746	0,7377	-0,3968	0,4181	0,1905	0,557	0,5289	0,6521	0,2525	0,6062	0,7896	-0,3059	0,505	UDIa
UDIe	1	-0,2157	-0,3936	-0,4084	0,3452	0,0043	-0,4615	-0,366	-0,2555	-0,3709	-0,4543	-0,1438	-0,2533	0,8136	-0,1572	UDIe
avg_lux200		1	0,4598	0,7692	-0,3465	0,3944	0,1882	0,5021	0,2563	0,3792	0,2358	0,5074	0,5787	-0,2652	0,7289	avg_lux200
avg_lux300			1	0,8486	-0,4078	0,2254	0,4093	0,4869	0,4997	0,702	0,4216	0,4301	0,4861	-0,3838	0,3351	avg_lux300
avg_lux				1	-0,4492	0,3667	0,4207	0,6227	0,5122	0,6587	0,4093	0,5226	0,6299	-0,4381	0,5855	avg_lux
blindsclosed					1	-0,3987	-0,3168	-0,3407	-0,1438	-0,1909	-0,449	-0,2156	-0,2953	0,3471	-0,2694	blindsclosed
SF%						1	0,1663	0,2768	0,1791	0,1518	0,2397	0,1766	0,2095	-0,1061	0,2486	SF%
DFmflat*							1	0,5204	0,5251	0,4038	0,2548	0,1479	0,2439	-0,4767	0,1372	DFmflat*
DFmh*								1	0,5327	0,5809	0,3299	0,5658	0,6759	-0,5371	0,5774	DFmh*
medianDF*									1	0,739	0,1468	0,3845	0,5076	-0,3317	0,1868	medianDF*
sDAh*										1	0,2905	0,5201	0,6564	-0,5027	0,2764	sDAh*
ASEh*											1	0,1715	0,2894	-0,4758	0,25	ASEh*
UDIf*												1	0,758	-0,2448	0,5574	UDIf*
UDIa*													1	-0,3548	0,6314	UDIa*
UDIe*														1	-0,1933	UDIe*
avg_lux200*															1	avg_lux200*

Figure 161 Spearman Variables Correlation. (Source: Elaboration by the author from Gretl) (in the followign pages).

	avg_lux300*	avg_lux*	blindsclosed*	SF%*	APE	HEATING	SYSTEMH	SOURCEH	COOLING	
IDAP	0,0514	0,0753	-0,0439	0,0812	-0,0037	0,0444	-0,0989	0,2399	-0,0804	IDAP
ZONE123	0,1039	0,1078	-0,1287	0,0035	0,003	-0,1715	-0,1009	0,0714	0,023	ZONE123
BUILDING_TYPOLOGY	0,2316	0,2196	-0,2096	0,1757	-0,0714	-0,4916	-0,1367	-0,0168	-0,0759	BUILDING_TYPOLOGY
FACADE_TYPOLOGY	0,0867	0,0773	0,0754	-0,045	-0,0095	0,0586	0,0922	0,1043	-0,0926	FACADE_TYPOLOGY
PRICE	0,1455	0,1192	0,1125	0,0619	0,0753	-0,1859	0,1766	0,0101	0,0825	PRICE
SURFACE	0,1692	0,1467	0,0989	0,0439	0,04	-0,1792	0,1431	0,0967	-0,0039	SURFACE
PRICESQM	0,0831	0,0557	0,0477	0,0011	0,2152	-0,0024	0,1358	-0,0994	0,11	PRICESQM
FLOOR_NUMBER	0,3281	0,4448	-0,165	0,4438	-0,1582	-0,2152	0,0748	0,172	0,1358	FLOOR_NUMBER
TOTAL_FLOOR	0,2451	0,2659	-0,0942	0,1435	-0,1049	-0,4675	-0,008	0,1718	-0,0013	TOTAL_FLOOR
LAST_FLOOR	0,0721	0,1981	-0,0255	0,1518	-0,1139	0,1909	0,0106	-0,0628	0,1689	LAST_FLOOR
CONSTRUCTION_YEAR	0,0739	0,0183	0,0167	-0,1156	0,1906	-0,0611	0,0408	0,0428	0,0875	CONSTRUCTION_YEAR
CATEGORY	0,1166	0,0755	-0,0303	0,0329	0,3259	-0,0839	0,2337	0,2863	0,0134	CATEGORY
CONSERVATION	-0,1849	-0,1884	0,1326	-0,0575	0,0825	0,1202	-0,0334	-0,1643	0,2318	CONSERVATION
ELEVATOR	0,2059	0,1781	-0,1001	0,0504	0,0008	-0,2215	0,0895	0,0152	-0,1033	ELEVATOR
GREEN	0,2644	0,2355	-0,0223	0,0296	0,0941	0,0322	0,0869	0,2809	-0,2478	GREEN
VIEW_OUT	0,3036	0,4538	-0,1869	0,3461	-0,1456	-0,0189	0,0147	0,189	0,0146	VIEW_OUT
NOISE_average	-0,0961	-0,1233	0,2227	-0,1993	0,1404	0,2961	0,2127	-0,1417	0,0646	NOISE_average
n_ROOMS	0,1049	0,0789	0,0827	0,0571	-0,0113	-0,1262	0,113	0,042	0,0098	n_ROOMS
BATHROOMS	0,0595	0,0439	0,2155	0,0032	0,0373	-0,0858	0,1569	-0,0095	-0,0233	BATHROOMS
KITCHEN	-0,0095	0,0492	0,1015	0,0556	0,0321	0,0167	-0,0435	0,0703	-0,013	KITCHEN
BALCONIES	-0,0483	0,089	0,085	0,2451	-0,2226	0,0226	-0,0751	0,018	-0,0695	BALCONIES
TERRACES	0,1435	0,0733	-0,0485	-0,1673	0,1938	-0,0648	0,0358	0,1161	-0,0082	TERRACES
ORIENTATION	0,1724	0,1436	-0,0971	0,199	0,0369	-0,2961	0,0365	0,1412	-0,0023	ORIENTATION
VIEWS	-0,0317	-0,0614	0,285	0,0037	0,0344	-0,084	0,1266	0,1638	-0,0569	VIEWS
GLAZING	-0,1107	-0,1229	-0,0863	0,336	0,0582	0,2138	0,0373	0,0611	0,197	GLAZING
FRAME	-0,0501	-0,0724	0,0062	0,2511	-0,0697	0,0884	-0,0049	-0,017	0,1743	FRAME
WFR	0,0533	0,0875	0,0007	0,0543	0,0465	-0,0941	0,0524	0,1274	-0,0513	WFR
WFRallflat	0,404	0,4334	-0,1122	0,1379	-0,0467	0,0092	-0,0251	0,0307	-0,1499	WFRallflat
DFmflat	0,6316	0,7252	-0,3581	0,4311	-0,0781	0,152	0,0186	0,1538	0,0821	DFmflat
DFmh	0,5261	0,6812	-0,2179	0,4293	-0,0191	0,0761	0,0942	0,1781	0,0668	DFmh
medianDF	0,4092	0,5067	0,0134	0,2602	-0,1559	0,0985	0,0624	-0,0037	-0,0455	medianDF
SDAh	0,6317	0,6396	-0,0488	0,2013	-0,1451	0,0391	0,0041	0,089	-0,1676	SDAh
ASEh	0,4135	0,4122	-0,3766	0,2207	-0,1139	0,0203	-0,0865	-0,0085	0,181	ASEh
UDIf	0,4508	0,5558	-0,1428	0,2285	0,119	0,0499	-0,0054	0,1856	-0,1384	UDIf
UDIa	0,5436	0,6661	-0,2439	0,2742	-0,0113	0,0275	0,0255	0,1664	-0,1412	UDIa
UDIe	-0,3297	-0,3995	0,2897	-0,0325	0,1427	0,1373	0,1343	0,0834	0,0044	UDIe
avg_lux200	0,4487	0,6435	-0,2277	0,2635	-0,053	0,0655	0,0856	0,122	0,0398	avg_lux200
avg_lux300	0,8562	0,7854	-0,3434	0,2014	-0,0032	0,0024	0,0555	0,124	-0,0246	avg_lux300
avg_lux	0,772	0,8842	-0,3569	0,2994	-0,0577	0,0533	0,055	0,0869	-0,0413	avg_lux
blindsclosed	-0,407	-0,4249	0,8713	-0,3577	0,073	0,049	0,0191	-0,1629	-0,0379	blindsclosed
SF%	0,1924	0,28	-0,299	0,7421	-0,0569	0,1124	0,0728	0,1642	0,1192	SF%
DFmflat_aaa	0,3504	0,4731	-0,3343	0,2431	-0,1103	0,0941	-0,0524	-0,0727	0,0513	DFmflat_aaa
DFmh*	0,5675	0,7506	-0,2962	0,3708	-0,0845	0,018	0,0473	0,1346	0,0383	DFmh*
medianDF*	0,4223	0,5562	-0,0463	0,2298	-0,0634	0,1281	0,0419	-0,0246	-0,0428	medianDF*
sDAh*	0,6768	0,7125	-0,1151	0,2094	-0,1432	0,0294	0,0147	0,1303	-0,1873	sDAh*
ASEh*	0,4842	0,4456	-0,4511	0,294	-0,1545	-0,0136	-0,0955	-0,0628	0,2217	ASEh*
UDIf*	0,4876	0,5926	-0,181	0,2733	0,067	-0,0655	-0,0947	0,2249	-0,0579	UDIf*
UDIa*	0,5642	0,7282	-0,2515	0,2797	0,0259	-0,0273	-0,0695	0,1543	-0,1039	UDIa*
UDIe*	-0,4325	-0,4983	0,3336	-0,1653	0,1969	0,0876	0,137	-0,022	0,0264	UDIe*
avg_lux200*	0,3914	0,6822	-0,2724	0,2751	-0,0488	-0,0546	-0,0106	0,0976	0,0422	avg_lux200*
avg_lux300*	1	0,861	-0,4328	0,3197	-0,061	-0,0607	0,0691	0,1086	-0,04	avg_lux300*
avg_lux*		1	-0,4022	0,3692	-0,0771	-0,0192	0,0325	0,0843	-0,02	avg_lux*
blindsclosed*			1	-0,3801	0,1171	0,052	0,0047	-0,1465	-0,0223	blindsclosed*
SF%*				1	-0,0373	-0,0124	0,0197	0,1215	0,1498	SF%*
APE					1	0,2556	0,086	0,0815	0,0598	APE
HEATING						1	0,0903	0,0365	0,0898	HEATING
SYSTEMH							1	0,0382	-0,0475	SYSTEMH
SOURCEH								1	-0,043	SOURCEH
COOLING									1	COOLING

Figure 162 Spearman Variables Correlation. (Source: Elaboration by the author from Gretl).

6.4.2 Outliers and Model Refinement

Outliers are data that differs from the rest of the observations. The outliers analysis is done through Box-plots in Gretl, and it is analyzed the dependent variable chosen, in this case the price per m² (PRICESQM), which has presented no outliers (*Figure 163*).

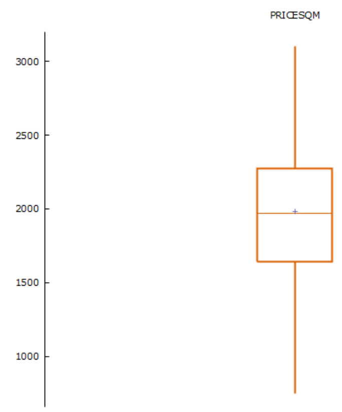


Figure 163 Box-Plot describing the price per m² data. (Source: Gretl from Author's elaborated data).

Secondly, the listing price (PRICE) alone is analyzed, presenting once again no outliers (*Figure 164*).

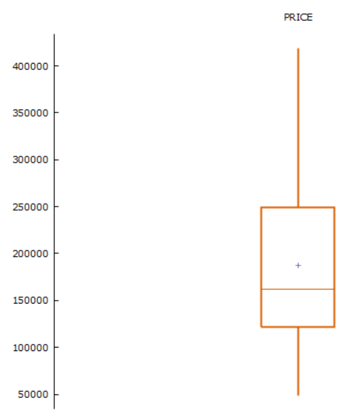


Figure 164 Box-Plot describing the listing prices data. (Source: Gretl from Author's elaborated data).

Lastly, even if not to be considered as a dependent variable, the surface (SURFACE) has been analyzed. The result is three outliers which overpass the rest of the observations, with surfaces of the units over 160 m². With a deeper analysis and checking each case singularly, the three observations are not to be disregarded because they are still part of the same price and market segment. If this was not the case, the data would have been removed from the model or substituted with new observations for keeping the sample consistent to 100 cases (*Figure 165*).

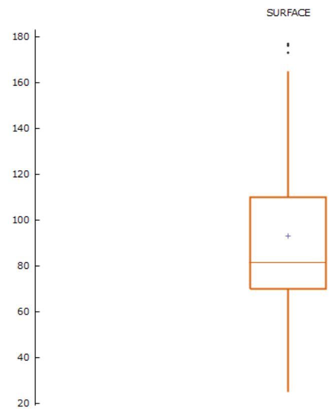


Figure 165 Box-Plot describing the surface data. (Source: Gretl from Author's elaborated data).

6.5 Multiple Regression Analysis Results

The next step is the Multiple Regression models using Gretl's standard Ordinary Least Squares Model (**OLS** - *minimi quadrati ordinari*). In Gretl, it is possible to create models indicating the chosen dependent variable and the independent variables (*regressori*). Initially, the dependent variable used is **price per m²**, while the independent variables have been carefully selected for them to be non-correlated and including daylighting variables (*Figure 166*).

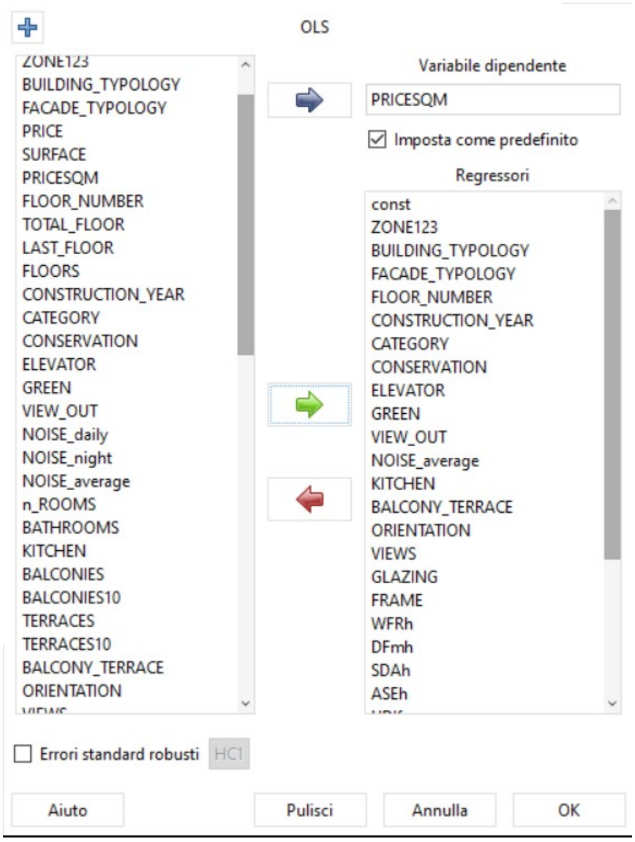


Figure 166 Dependent and independent variables are selected to be inserted into the model. (Source: Gretl from Author's elaborated data).

```
Modello 1: OLS, usando le osservazioni 1-100
Variabile dipendente: PRICESQM

                     coefficiente  errore std.  rapporto t  p-value
  -----------------------------------------------------------------
  const                827,577      573,500       1,443     0,1535
  ZONE123              -47,5191      57,2042     -0,8307    0,4090
  BUILDING_TYPOLOGY    -55,4429     133,678      -0,4147    0,6796
  FACADE_TYPOLOGY       44,6737      45,2884      0,9864    0,3274
  FLOOR_NUMBER          25,2785      27,5382      0,9179    0,3618
  CONSTRUCTION_YEAR     29,5575      65,5390      0,4510    0,6534
  CATEGORY             -47,7509      61,9868     -0,7703    0,4437
  CONSERVATION         293,524       68,7128      4,272     6,08e-05 ***
  ELEVATOR             666,397      142,835       4,665     1,46e-05 ***
  GREEN                 35,8072     100,012       0,3580    0,7214
  VIEW_OUT             -23,3285      86,6118     -0,2693    0,7885
  NOISE_average        -23,5363      82,3437     -0,2858    0,7759
  KITCHEN                3,19278     41,8235      0,07634   0,9394
  BALCONY_TERRACE     -149,843      310,951      -0,4819    0,6314
  ORIENTATION           16,4804      44,4287      0,3709    0,7118
  VIEWS                154,510      100,012       1,545     0,1269
  GLAZING               -9,47071    108,884      -0,08698   0,9309
  FRAME                -83,8036      62,6830     -1,337     0,1856
  WFRh                  67,9513      79,4211      0,8556    0,3952
  DFmh                -129,535      107,419      -1,206     0,2320
  SDAh                 -42,8526      97,5259     -0,4394    0,6617
  ASEh                 218,015      153,191       1,423     0,1592
  UDIf                 -14,4706      95,0511     -0,1522    0,8794
  UDIe                -150,193      181,886      -0,8258    0,4118
  blindsclosed         -37,5723      89,4348     -0,4201    0,6757
  SF                     9,92260     88,5107      0,1121    0,9111
  APE                  160,373       72,9383      2,199     0,0313   **
  HEATING               89,0494     148,377       0,6002    0,5504
  SYSTEMH               85,6177      87,5016      0,9785    0,3313
  SOURCEH              -54,9027      58,0345     -0,9460    0,3474
  COOLING               79,9884      94,1694      0,8494    0,3986

Media var. dipendente   1983,622   SQM var. dipendente    502,0962
Somma quadr. residui     8861770   E.S. della regressione 358,3733
R-quadro                0,644932   R-quadro corretto      0,490555
F(30, 69)               4,177635   P-value(F)             4,78e-07
Log-verosimiglianza    -711,4982   Criterio di Akaike     1484,996
Criterio di Schwarz     1565,757   Hannan-Quinn           1517,682
Note: SQM = scarto quadratico medio; E.S. = errore standard

Escludendo la costante, il p-value è massimo per la variabile 23 (KITCHEN)
```

Figure 167 First model example. (Source: Gretl from Author's elaborated data).

Every model output will result as *Figure 167*, through a table where each row corresponds to one independent variable and contains the estimates, and each column contains the results of the coefficient estimates and standard errors[189]. The last line at the bottom of *Figure 167* indicates the suggested independent variable not significant enough and to be removed according to the highest value in the column ***p-value***. The lowest *p-values* are the most significant variables to be kept and indicated also by the symbol '*', where '***' is the most significant variable and with lower values. Continuing this process until all variables' results are significant is the solution, even though some results could still be obtained where one or more variables lack significance. The aim of this study, in fact, is to include the new variables introduced along this research and study their behavior in relation to the more *classic variables*, and whether they would result significant or not a result would always be achieved.

Here it follows the process of **stepwise regression**, with multiple models to be commented on until reaching the best results. Along with checking the significance of variables, the information provided by the model which needs particular attention is the **corrected determination index R_c^2** (*R-quadro corretto*), which the higher, the better it is since it expresses in percentage the value of explanation of the market.

In addition, particular attention is to be taken for the **Akaike Criterion** and for the **Schwarz's Criterion**, which values results to be preferred is the lowest. The models are developed until the complete refinement. The *Coefficient* column represents the implicit marginal price of each variable included in the model, if positive and the higher it is, the higher implicit marginal price the variable detain. It can also be negative, indicating a negative implicit marginal price in regards to the variable considered.

189 A. Cottrell, R. Lucchetti, (2023), *Gretl User's Guide - Gnu Regression, Econometrics and Time-series Library*, p. 17.

Multiple Regression Model 1: OLS, using the whole dataset

(observations 1-100)

Dependent Variable: **PRICESQM**

	Coefficient	*Std. Error*	*t ratio*	*p-value*	
const	557,232	206,013	2,705	0,0081	***
CONSERVATION	316,711	57,8006	5,479	<0,0001	***
ELEVATOR	672,407	95,2024	7,063	<0,0001	***
FRAME	−88,4889	39,7668	−2,225	0,0285	**
APE	151,424	55,3479	2,736	0,0075	***
FACADE_TYPOLOGY	64,6237	33,3915	1,935	0,0560	*
DFmflat	−72,0352	62,1071	−1,160	0,2491	
ASEh	236,810	97,0157	2,441	0,0166	**

average dependent variable	1983,622	D.S. dependent variable	502,0962
residual sum of squares	10332993	regression S.E.	335,1345
R^2	0,585984	R_c^2	0,554483
F(7, 92)	18,60195	P-value(F)	3,12e-15
Log-likelihood	−719,1780	Akaike Criterion	1454,356
Schwarz Criterion	1475,197	Hannan-Quinn	1462,791

Figure 168 Multiple Regression Model 1 (Source: Gretl from Author's elaborated data).

In this first model (*Figure 168*), the *average Daylight Factor of the whole unit* (DFmflat) does not result significant, and its implicit marginal price is also negative. This is the opposite of what was expected, since the higher the Daylight Factor of the unit, the 'better' the daylight conditions should be.

The other significant variables obtained are:

- the *state of conservation* of the unit (CONSERVATION);
- the *presence of the elevator* (ELEVATOR);
- the *frame typology* (FRAME);
- the *APE Certification* (APE);
- the *Façade Typology* (FACADE_TYPOLOGY);
- and the *Annual Sunlight Exposure of the regularly occupied areas* (ASEh).

The determination index R^2 equals 0,58, while the corrected determination index R_c^2 0,55. The Schwarz Criterion is 1475,19, while the Akaike Criterion 1454,35.

During these preliminary analyses of the introduction of new variables, changes have been done to their classifications, for example transforming them into dichotomic variables instead of having 3-4 levels, in order to achieve their significance. This was made in relation to the *average illuminance* variable (avg_lux). Initially it has been divided into four categories:

- 1 when <200 lux;
- 2 when between 200 and 400 lux;
- 3 when between 400 and 500 lux;
- 4 when >500 lux.

This variable has then been transformed in dichotomic, where 1 has been assigned when 300 lux were achieved (avg_lux300) (*Figure 169*).

Multiple Regression Model 2: OLS, using the whole dataset

(observations 1-100)

Dependent Variable: **PRICESQM**

	Coefficient	*Std. Error*	*t ratio*	*p-value*	
const	308,429	229,254	1,345	0,1819	
CONSERVATION	339,999	57,7081	5,892	<0,0001	***
ELEVATOR	645,482	96,1667	6,712	<0,0001	***
FACADE_TYPOLOGY	71,4168	32,9351	2,168	0,0328	**
BALCONIES	97,6102	39,3826	2,479	0,0151	**
TERRACES	113,283	57,8960	1,957	0,0535	*
FRAME	−90,4426	39,0359	−2,317	0,0228	**
APE	163,094	55,9510	2,915	0,0045	***
DFmflat	−73,4717	74,6969	−0,9836	0,3280	
ASEh	292,107	105,979	2,756	0,0071	***
avg_lux300	−46,1979	106,524	−0,4337	0,6656	

average dependent variable	1983,622	D.S. dependent variable	502,0962
residual sum of squares	9600742	regression S.E.	328,4410
R^2	0,615323	R_c^2	**0,572101**
F(10, 89)	14,23632	P-value(F)	1,06e-14
Log-likelihood	−715,5029	Akaike Criterion	1453,006
Schwarz Criterion	1481,663	Hannan-Quinn	1464,604

Figure 169 Multiple Regression Model 2 (Source: Gretl from Author's elaborated data).

After this second model, the *average Daylight Factor of the whole unit* (DFmflat) is once again not significant, together with the *average illuminance* (avg_lux300) and the ***constant*** (const), which should always be significant. Although the corrected determination index R_c^2 increased to 0,57, this model is not acceptable. The average illuminance is once again introduced in the model, but with a dichotomic variable where '1' is obtained with lux over 200 lux only (avg_lux200) (*Figure 170*).

Multiple Regression Model 3: OLS, using the whole dataset

(observations 1-100)

Dependent Variable: **PRICESQM**

	Coefficient	*Std. Error*	*t ratio*	*p-value*	
const	342,716	220,026	1,558	0,1229	
CONSERVATION	340,339	57,4854	5,920	<0,0001	***
ELEVATOR	639,385	94,9378	6,735	<0,0001	***
FACADE_TYPOLOGY	72,4975	32,9083	2,203	0,0302	**
BALCONIES	99,6096	39,4118	2,527	0,0133	**
TERRACES	112,882	56,8014	1,987	0,0500	**
FRAME	−86,9108	39,3066	−2,211	0,0296	**
APE	161,445	55,7026	2,898	0,0047	***
DFmflat	−137,369	86,1894	−1,594	0,1145	
ASEh	272,797	96,0699	2,840	0,0056	***
avg_lux200	77,4838	103,033	0,7520	0,4540	

average dependent variable	1983,622	D.S. dependent variable	502,0962
residual sum of squares	9560280	regression S.E.	327,7482
R^2	0,616945	R_c^2	**0,573905**
F(10, 90)	14,33424	P-value(F)	8,87e-15
Log-likelihood	−715,2917	Akaike Criterion	1452,583
Schwarz Criterion	1481,240	Hannan-Quinn	1464,181

Figure 170 Multiple Regression Model 3 (Source: Gretl from Author's elaborated data).

The corrected determination index R_c^2 is seeing once again an increase compared to the first model, but once again the *average Daylight Factor* of the unit (DFmflat) and the *average illuminance* (avg_lux200) do not result significative, together with the *constant* (const).

For this reason, the dependent variable has been substituted by the ***logarithmic of the price per m²*** (**l_PRICESQM**), and the model 4 is obtained (*Figure 171*).

Multiple Regression Model 4: OLS, using the whole dataset

(observations 1-100)

Dependent Variable: **l_PRICESQM**

	Coefficient	*Std. Error*	*t ratio*	*p-value*	
const	6,68972	0,117659	56,86	<0,0001	***
CONSERVATION	0,178629	0,0307516	5,809	<0,0001	***
ELEVATOR	0,372564	0,0508107	7,332	<0,0001	***
FACADE_TYPOLOGY	0,0404884	0,0175601	2,306	0,0234	**
BALCONIES	0,0605569	0,0210300	2,880	0,0050	***
TERRACES	0,0689521	0,0301886	1,284	0,0247	**
FRAME	−0,0514814	0,0208379	−2,471	0,0154	**
ASEh	0,144096	0,0514166	2,803	0,0062	***
APE	0,0741489	0,0298121	2,487	0,0147	**
DFmflat	−0,0683231	0,0328454	−2,080	0,0404	**

average dependent variable	7,557532	D.S. dependent variable	0,276541
residual sum of squares	2,769207	regression S.E.	0,175411
R^2	0,634235	R_c^2	**0,597659**
F(9, 90)	17,33999	P-value(F)	2,92e-16
Log-likelihood	37,43660	Akaike Criterion	−54,87320
Schwarz Criterion	−28,82150	Hannan-Quinn	−44,32961

Figure 171 Multiple Regression Model 4 (Source: Gretl from Author's elaborated data).

The corrected determination index R_c^2 is 0,59, the Akaike Criterion -54,87, and the Schwarz Criterion -28,82. These results show a clear improvement compared to the previous model.

Analyzing the implicit marginal coefficients, the results show two variables with a negative result, the window *frame typology* (FRAME) and the *average Daylight Factor of the whole unit* (DFmflat). While the result regarding the frame typology can be explained, the result of the Daylight Factor cannot, since it would mean the lower the Daylight Factor percentage, the better, which is not the case here. For this reason, the variable *average Daylight Factor* (DFmflat) have been substituted with another significant variable among the *new variables* introduced in this study.

Multiple Regression Model 5: OLS, using the whole dataset

(observations 1-100)

Dependent Variable: **l_PRICESQM**

	Coefficient	*Std. Error*	*t ratio*	*p-value*	
const	6,67469	0,118827	56,17	<0,0001	***
CONSERVATION	0,179263	0,0309763	5,787	<0,0001	***
ELEVATOR	0,379520	0,0511030	7,427	<0,0001	***
FACADE_TYPOLOGY	0,0359729	0,0175659	2,048	0,0435	**
FRAME	−0,0523661	0,0210314	−2,490	0,0146	**
ASEh	0,135637	0,0514062	2,639	0,0098	***
APE	0,0796181	0,0300464	2,650	0,0095	***
BALCONIES	0,0649137	0,0216915	2,993	0,0036	***
TERRACES	0,0678754	0,0304450	2,229	0,0283	**
UDIa	−0,0417721	0,0243315	−1,717	0,0895	*

average dependent variable	7,557532	D.S. dependent variable	0,276541
residual sum of squares	2,810310	regression S.E.	0,176708
R^2	0,628806	R_c^2	**0,591687**
F(10, 90)	16,94012	P-value(F)	5,51e-16
Log-likelihood	36,69991	Akaike Criterion	−53,39982
Schwarz Criterion	−27,34812	Hannan-Quinn	−42,85623

Figure 172 Multiple Regression Model 5 (Source: Gretl from Author's elaborated data).

In *Figure 172* the model 5 has all significant variables and has as dependent variable the **logarithm of price per m²** (**l_PRICESQM**). The corrected determination index R_c^2 is 0,59, the Akaike Criterion is -53,39, and the Schwarz Criterion is -27,34. This model, if compared with the previous models, is to be preferred because the R_c^2 is higher and both the criteria are lower.

The most significant variables with the lowest *p-value* indicated by "***" are:

- the *state of conservation of the unit* (CONSERVATION);
- the *presence of the elevator* (ELEVATOR);
- the *Annual Sunlight Exposure* ($ASE_{1000,250h}$) for the regularly occupied spaces (ASEh);
- the *APE Certification Level* (APE);
- and the *number of balconies* (BALCONIES).

The other variables are:

- the *façade typology* ** (FACADE_TYPOLOGY);
- the *window frame typology* ** (FRAME);
- the *number of terraces* ** (TERRACES);

- and the *Useful Daylight Illuminance achieved* * (UDIa).

The implicit marginal prices are once again all positive, with the exception of the window *frame typology* (FRAME), and of the *Useful Daylight Illuminance achieved* (UDIa). The **UDIa** variable expresses the percentage of lux between 100 and 3000 lux in the unit and it has been expressed as:

1: The 'critical' category between 0 and 20%.

2: The 'average' between 20 and 50%.

3: When it is higher than 50% it is the 'optimal'.

The higher the category, the better it is. In the implicit marginal coefficient found, instead, this is not reflected since it is equal to -0,04. This indicates that it has almost no influence in the total listing price of a housing unit compared to all the other variables, while still being significant.

In addition to the significant variables explained in the previous model, this model saw the introduction of the significance of the variables *balconies-terraces* (BALCONIES) (TERRACES). They both describe the **number of balconies or terraces** present in the units of the data sample. Their significance states the importance buyers are giving nowadays to a private outdoor space, especially after the Covid-19 situation.

6.5.1 Final Multiple Regression Model

After developing various Multiple Regression models, the following model has been chosen to best represent the final result of this research.

Multiple Regression Model 6: OLS, using the whole dataset

(observations 1-100)

Dependent Variable: **PRICESQM**

	Coefficient	*Std. Error*	*t ratio*	*p-value*	
const	441,733	180,682	2,445	0,0164	**
CONSERVATION	319,448	57,8596	5,521	<0,0001	***
ELEVATOR	675,951	95,3298	7,091	<0,0001	***
FRAME	−86,5986	39,8071	−2,175	0,0321	**
APE	153,897	55,4094	2,777	0,0066	***
FACADE_TYPOLOGY	60,4977	33,2631	1,819	0,0722	*
ASEh	197,418	91,0454	2,168	0,0327	**

average dependent variable	1983,622	D.S. dependent variable	502,0962
residual sum of squares	10484087	regression S.E.	335,7560
R^2	0,579930	R_c^2	**0,552829**
F(10, 90)	21,39863	P-value(F)	1,22e-15
Log-likelihood	−719,9038	Akaike Criterion	1453,808
Schwarz Criterion	1472,044	Hannan-Quinn	1461,188

Figure 173 Multiple Regression Model 6 (Source: Gretl from Author's elaborated data).

In *Figure 173* the Model 6 has as dependent variable the **price per m² (PRICESQM).** The corrected determination index R_c^2 is 0,55, the Akaike Criterion 1453,80, and the Schwarz Criterion 1472,04.

The most significant variables with the lowest *p-value* indicated by "***" are:

- the *state of conservation of the unit* (CONSERVATION);
- the *presence of the elevator* (ELEVATOR);
- and the *APE Certification Level* (APE).

The other variables included are:

- the *window frame typology* ** (FRAME);
- the *Annual Sunlight Exposure* $ASE_{1000,250h}$ of the regularly occupied spaces of the unit **(ASEh);
- and the *façade typology* *(FACADE_TYPOLOGY).

The marginal coefficients are all positive, meaning that with the increase of the categories a higher value is obtained, with only one exception.

For example, in the case of the **APE** Certification (APE), '1' is for classes E-F-G, '2' for classes C-D, and '3' for classes A-B. The higher the number is, the higher is the unit certification level. The similar approach also describes the **state of conservation** (CONSERVATION), where the higher the category, the better are the unit's conditions. The presence of the elevator (ELEVATOR) is a variable commonly significant in literature as well.

The other variables are all new variables introduced in this study.

The ***façade typology*** (FACADE_TYPOLOGY) levels describe the different categories according to their appearance, without necessarily being a classification neither representing the preference of the consumers, and this may be represented by the implicit marginal value obtained which, however positive, is still much smaller compared to the other values that have been found.

The ***Annual Sunlight Exposure*** $ASE_{1000,250h}$ (ASEh) of the regularly occupied spaces of the unit is a dichotomic variable where '1' is obtained when the result is higher than 10%, and the implicit marginal coefficient related to this variable reaches 197,418.

Finally, the only exception in the model with a negative implicit marginal coefficient is once again the ***window frame typology*** (FRAME). In the database it has been expressed as:

- '1' when the window frame is in wood;
- '2' when it is in Aluminum;
- finally '3' when in PVC.

The negative coefficient expresses the fact that buyers when buying a new house do prefer window frames in wood, instead of PVC and Aluminum. This is given both by the visual aesthetic and the material durability, as well as the thermal comfort guaranteed by the wooden choice.

6.6 Summary

In this Chapter the passages for the completion of the database of the data sample have been clearly explained, from the 3D Modeling in Revit and Rhino 7, to the simulations' settings and execution. Once all the simulations' results are inserted into the database, this is cleaned and prepared for Gretl. The variables' correlation is found, the outliers analysis is carried out, and finally the Multiple Regression models are analyzed. After multiple models and the introduction of the new variables, the final model is found, demonstrating the success of this study.

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Chapter 7
Discussion and Conclusion

Daylight is well-known for having a big relevance for the human well-being, as well as it being a feature buyers consider when searching for a new residential unit. It is essential in the architectural field, from the early stages of design and along all the life cycle of a building. The thesis' main objective has been demonstrating the importance of daylight in the real estate market, taking as case study the district *Pozzo Strada* in Turin, integrating the previous studies done in working environments and spreading it into the residential units as well. In *PART I* the theoretical aspects related to natural light, and the norms and regulations containing indications about daylight have been examined in depth, together with the Multiple Regression Analysis.

This study aimed at replying to these two questions reported in *Chapter 4*:

"*How can daylight be properly quantified and which are the limitations?*"

"*Can daylight be considered as a value in the real estate market and not only as a descriptive characteristic?*"

During the development of the Case Study in *PART II*, all the main daylight metrics, from the static Daylight Factor, to the more complex climate-based metrics, such as the spatial Daylight Autonomy (sDA), the Annual Sunlight Exposure (ASE), and the Useful Daylight Illuminance (UDI), have been explained and integrated in the data sample through simulations. Their inclusion on Multiple Regression analysis aimed at demonstrating their capability of having a monetary role, assessed from the implicit marginal price, corresponding in the Multiple Regression models in the coefficients' column, whilst confirming their worth as previously done in working environments.

Through the use of Multiple Regression analysis all the new *green variables* introduced in this study have been inserted in the Multiple Regression Models, avoiding the correlation of the variables. Many of them didn't result significant in the final model, such as the *average illuminance* (avg_lux). Others, instead, showed a very positive result, such in the case of the *façade typology* (FACADE_TYPOLOGY), the *frame typology* (FRAME), and the *Annual Sunlight Exposure of the regularly occupied areas* (ASEh), as well as in a minor extent the *Useful Daylight Illuminance achieved* (UDIa). The *average Daylight Factor* considering the whole unit (DFmflat), instead, together with the *window to floor ratio* (WFR) (RAI in Italian), which are widely considered in Italian norms and regulations, have not resulted as significant as climate-based metrics, and have been, for this reason, excluded from the final model.
The main limitations of this study have been: the approximation of the simulations' results due to the scarcity of data, followed by the number of the data sample. The database of 100 units has been chosen as representative of the *population*, and the units have been selected by the author's discretion following the completeness of the information provided by the advertisements. The research is based on the listing price of the housing units, which could differ significantly from the selling price, but which information is not easily found in the Italian real estate market.
Future developments of this study can include the increase of the data sample, expanding the research in other areas of Turin, as well as in other cities, in order to be able to include also the location within the significant variables, and obtaining a higher statistical significance, and for the variables to explain a larger share of the real estate market. With the results achieved, 55% of the real estate market has been explained, as it has been defined by the *corrected determination index* (R_c^2 of 0,55).

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Annex A
Extensive Dataset and Simulation Results

i. location

Variable name	Description	Type of variable	Categories	Numerical codings
IDAP	Identification of the unit	Counting		
LINK	Link of the adv	Nominal		
Municipality	Turin	Nominal	Turin	1
Area	D7 - *Pozzo Strada*	Nominal	D7 (OMI)	1
Micro-Areas	*Pozzo Strada* and the 3 micro-areas	Ordinal	Rivoli	1
			Monte Cucco - Bardonecchia	2
			Ruffini	3
Date	Date of advertisement	Ordinal		
Address	Address of the unit	Nominal		
Coordinates	Coordinates of the unit	Numerical		

ii. context

Variable name	Description	Type of variable	Categories	Numerical codings	Notes
Building typology	Typologies of residential units	Ordinal			
			"a ballatoio"	1	
			pluri-family	2	4 to 6 apartments
			multi-storey	3	more than 6 apartments (tower)
Facade typology	Historical - Architectural typology	Ordinal			
			Category 1	1	verticalism, simplicity
			Category 2	2	details and decoration, higher indoor heights
			Category 3	3	horizontalism, articulation of balconies and volumes
			Category 4	4	balcony all facade long
Price	Listing price (€)	Numerical continuous			
Surface	Commercial surface (sqm)	Numerical continuous			
Price/sqm	Price per square meter (€/sqm)	Numerical			
Floor of the unit	Floor	Numerical			
Total number of floors	Total number of floors of the building	Numerical			
Last floor	Last floor of the building	Dichotomic			
			Yes	1	
			No	0	
Floors	Floors of the apartment	Ordinal			
			Floor 0 - 0.5	1	
			Intermediate Floor	2	
			Last Floor - Mansard	3	
Year of construction	Year of construction	Ordinal			
			1919-1945	1	
			1946-1960	2	
			1961-1990	3	
			1990-2000	4	
			after 2000	5	
Building category	Category of the building	Ordinal			
			Popular-Economic	1	
			Medium	2	
			Lordly-Precious	3	
State of conservation of the unit	State of conservation of the unit	Ordinal			
			To be renovated (totally or partially)	1	
			Good condition / Habitable	2	
			Excellent condition / Renovated	3	
			New / In construction	4	
Elevator	Presence of the elevator	Dichotomic			
			Yes	1	
			No	0	
Green Area	Presence of the green area	Dichotomic			
			No	0	
			Shared	1	
View out	Levels of quality of the view	Ordinal			
			landscape layer (urban and/or nature)	1	Low floors, facing garages/walls/secondary streets
			landscape layer + 1 (sky or terrain)	2	Medium floors, facing corso/green
			all layers	3	High floors, 360° view,

Figure 174 Metadata for location and context. (Source: Elaboration by the Author).

(continue in the next pages)

iii. noise pollution

Variable name	Description	Type of variable	Categories	Numerical codings	Notes
Daily Noise Pollution	Noise pollution on the streets based on Arpa	Ordinal			Intervals
			very light	1	<35 - 49 dB(A)
			medium	2	50 - 64 dB(A)
			very high	3	65 - >80 dB(A)
Nocturnal Noise Pollution	Noise pollution on the streets based on Arpa	Ordinal			Intervals
			very light	1	<35 - 49 dB(A)
			medium	2	50 - 64 dB(A)
			very high	3	65 - >80 dB(A)
Average Noise Pollution	Noise pollution on the streets based on Arpa	Ordinal			Intervals
			very light	1	<35 - 49 dB(A)
			medium	2	50 - 64 dB(A)
			very high	3	65 - >80 dB(A)

iv. apartment layout

Variable name	Description	Type of variable	Categories	Numerical codings
Number of rooms	Number of rooms	Numerical discreet		
Bathrooms	Number of bathrooms	Numerical discreet		
Kitchen	Typology	Ordinal		
			Kitchen corner	1
			Kitchenette	2
			Semi - habitable	3
			Habitable	4
Balconies	Number of balconies (depth <1.40m)	Numerical discreet		
	Presence of the balcony	Dichotomic		
			Absent	0
			Present	1
Terraces	Number of terraces (depth >1.40m)	Numerical discreet		
	Presence of the terrace	Dichotomic		
			Absent	0
			Present	1
Balcony or Terrace	Presence of at least one balcony or terrace	Dichotomic		
			Absent	0
			Present	1

v. daylight

Variable name	Description	Type of variable	Categories	Numerical codings
Orientation	Orientation of the apartment	Nominal descriptive		
			East-West	1
			North-South	2
			North East - South West	3
			North West - South East	4
Views	Number of views	Numerical discreet		
Glazing	Type of glazing	Ordinal		
			Single Glazing	1
			Double Glazing	2
Window Frame	Window Frame typology	Nominal descriptive		
			Wood	1
			Aluminum	2
			PVC	3

Figure 175 Metadata for noise pollution, apartment layout, and daylight. (Source: Elaboration by the Author).

vi. daylight simulations
with and without obstructions

Variable name	Description	Type of variable	Categories	Numerical codings	Notes
WFR	Window to Floor ratio > 1/8	Dichotomic	<1/8	0	does not comply
			>1/8	1	comply to regulations
WFR all apartment	Window to Floor ratio > 1/8	Ordinal	<0.1	0	does not comply
			0.1-0.15	1	comply to regulations
			>1.5	2	high performance
WFR regularly occupied areas	Window to Floor ratio > 1/8	Ordinal	<0.1	0	does not comply
			0.1-0.15	1	comply to regulations
			>1.5	2	high performance
DFm % all apartment	average Daylight Factor of the entire apartment	Ordinal	0-1%	1	poor
			1-2%	2	average
			2-3%	3	good
			>3%	4	high
DFm % regularly occupied areas	average Daylight Factor	Ordinal	0-1%	1	poor
			1-2%	2	average
			2-3%	3	good
			>3%	4	high
DF % median	median Daylight Factor of the entire apartment	Ordinal	0-1%	1	poor
			1-2%	2	average
			2-3%	3	good
			>3%	4	high
Spatial Daylight Autonomy regularly occupied areas	sDA300,50%	Ordinal	<40%	1	poor
			40-55%	2	average
			55-75%	3	good
			>75%	4	high
Annual Sunlight Exposure regularly occupied areas	ASE1000,250h	Dichotomic	<10%	0	
			>10%	1	
Useful Daylight Illuminance fell-short	UDI.f	Ordinal	60-100%	1	critic
			30-60%	2	average
			0-30%	3	optimal
Useful Daylight Illuminance achieved	UDI.a	Ordinal	0-15	1	critic
			15-30	2	average
			30-50	3	good
			>50	4	optimal
Useful Daylight Illuminance exceeded	UDI.e	Ordinal	>75%	0	critic
			<75%	1	acceptable
Average Illuminance	Average Illuminance (lux)	Ordinal	<200	1	poor
			200-400	2	acceptable
			400-500	3	high
			>500	4	very high

Figure 176a Metadata for daylight simulations. (Source: Elaboration by the Author).

(continue in the next pages)

Variable name	Description	Type of variable	Categories	Numerical codings	
Blinds closed	% of blinds being used for excess of daylight	Ordinal	>20%	1	excessive use
			10-20%	2	normal use
			<10%	3	minimal/absent use
Sky View Factor on facades weighted for all facades with significant openings	Sky View Factor SVF (%)	Ordinal	0-15%	0	critic
			15-27%	1	average
			>27%	2	optimal

vii. energy efficiency

Variable name	Description	Type of variable	Categories	Numerical codings
Energy performance of the building	EPBD (APE)	Ordinal	E-F-G	1
			C-D	2
			A-B	3
Heating typology	Heating typology	Ordinal	Centralized	1
			Autonomous	2
Heating system typology	Heating system typology	Ordinal	Radiators	1
			Radiant Panels in the floor	2
			Air Systems	3
Heating source	Source typology	Ordinal	Methane	1
			Teleheating	2
			Gas	3
Cooling	Cooling	Dichotomic	Absent	0
			Present / Predisposition	1

Figure 176b Metadata for daylight simulations and energy efficiency. (Source: Elaboration by the Author).

IDAP	LINK	MUNICIPALITY	AREA	ZONE123	DATE	ADDRESS	Coordinate X	Coordinate Y
1	https://www.immobiliare.it/annunci/99231128/	1	1	1	18/11/2022	via Mattie 12	45,073515	7,636045
2	https://www.immobiliare.it/annunci/99337666/	1	1	1	18/11/2022	corso Trapani 26	45,073337	7,641309
3	https://www.immobiliare.it/annunci/98755056/	1	1	1	22/10/2022	via Almese 9	45,074717	7,65258
4	https://www.immobiliare.it/annunci/96678060/	1	1	2	22/10/2022	via Monginevro 199	45,064139	7,62758
5	https://www.immobiliare.it/annunci/98633966/	1	1	3	22/11/2022	via Sestriere 29	45,06684412	7,638518127
6	https://www.immobiliare.it/annunci/98696542/	1	1	2	22/10/2022	corso Filippo Brunelleschi 29	45,072202	7,623504
7	https://www.immobiliare.it/annunci/96442066/	1	1	2	22/10/2022	via Valgioie 89	45,076701	7,625994
8	https://www.immobiliare.it/annunci/88714195/	1	1	3	22/10/2022	corso Trapani 140	45,065551	7,636647
9	https://www.immobiliare.it/annunci/94744100/	1	1	3	21/10/2022	via Monte Ortigara 1	45,066169	7,636534
10	https://www.immobiliare.it/annunci/98985600/	1	1	1	21/10/2022	corso Vittorio Emanuele II 233	45,07430357	7,644704478
11	https://www.immobiliare.it/annunci/89010749/	1	1	1	21/10/2022	via Mattie 23	45,073255	7,635162
12	https://www.immobiliare.it/annunci/99525644/	1	1	1	17/11/2022	via Groscavallo 16	45,072995	7,652273
13	https://www.immobiliare.it/annunci/98583618/	1	1	1	22/10/2022	corso Peschiera 284	45,070709	7,634507
14	https://www.immobiliare.it/annunci/98750084/	1	1	2	22/10/2022	corso Filippo Brunelleschi 129	45.064085	7.626821
15	https://www.immobiliare.it/annunci/97024636/	1	1	2	12/12/2022	via Valgioie 71	45,07645326	7,627882389
16	https://www.immobiliare.it/annunci/99540992/	1	1	1	18/11/2022	corso Vittorio Emanuele II 190	45,073595	7,649305
17	https://www.immobiliare.it/annunci/98826218/	1	1	1	21/10/2022	via Digione 8;sc B	45,07645757	7,651599799
18	https://www.immobiliare.it/annunci/98984730/	1	1	1	21/10/2022	via Digione 8;sc B	45,07645757	7,651599799
19	https://www.immobiliare.it/annunci/91725566/	1	1	1	21/10/2022	via Bruino 30	45,073628	7.654789
20	https://www.immobiliare.it/annunci/99026858/	1	1	2	21/10/2022	corso Filippo Brunelleschi 95	45,067	7,625286
21	https://www.immobiliare.it/annunci/99039108/	1	1	1	21/10/2022	via Camburzano 7	45,076475	7,647885
22	https://www.immobiliare.it/annunci/95962850/	1	1	2	21/10/2022	corso Francia 288	45,074976	7,625004
23	https://www.immobiliare.it/annunci/98933950/	1	1	2	20/10/2022	via Monginevro 203	45,064152	7.62709
24	https://www.immobiliare.it/annunci/97654786/	1	1	1	20/10/2022	via Enrico Cialdini 11 scala B	45,073101	7,654346
25	https://www.immobiliare.it/annunci/97221112/	1	1	2	20/10/2022	corso Filippo Brunelleschi 143	45,063411	7,627283
26	https://www.immobiliare.it/annunci/95348962/	1	1	2	20/10/2022	corso Filippo Brunelleschi 91	45,067282	7,625139
27	https://www.immobiliare.it/annunci/96417886/	1	1	2	20/10/2022	via Medardo Rosso 5	45,071537	7,630304
28	https://www.immobiliare.it/annunci/75290708/	1	1	3	20/10/2022	corso Monte Cucco 115	45,064263	7,631287
29	https://www.immobiliare.it/annunci/98847492/	1	1	1	20/10/2022	corso vittorio Emanuele II 182	45,07328	7,650179
30	https://www.immobiliare.it/annunci/99017042/	1	1	3	20/10/2022	corso Trapani 128	45,066518	7,637072
31	https://www.immobiliare.it/annunci/98981454/	1	1	2	19/10/2022	via Guido Rey 8	45,074413	7,633847
32	https://www.immobiliare.it/annunci/98536350/	1	1	2	19/10/2022	via Sagra di S. Michele 128	45,064028	7,628223
33	https://www.immobiliare.it/annunci/98984054/	1	1	3	19/10/2022	via Matilde Serao 24	45,063718	7,633086
34	https://www.immobiliare.it/annunci/98953266/	1	1	2	19/10/2022	corso Peschiera 309	45,07224175	7,629264541
35	https://www.immobiliare.it/annunci/97148204/	1	1	2	20/10/2022	corso Francia 270	45,0751434	7.6272074
36	https://www.immobiliare.it/annunci/92028838/	1	1	1	20/10/2022	via Federico Paolini 14 A	45,072868	7,65366
37	https://www.immobiliare.it/annunci/98483944/	1	1	3	20/10/2022	via Candido Viberti 13	45,067843	7.636462
38	https://www.immobiliare.it/annunci/98744392/	1	1	1	20/10/2022	via Lera 22	45,073888	7,639514
39	https://www.immobiliare.it/annunci/98431920/	1	1	2	4/10/2022	corso Monte Cucco 64/B	45,06970971	7,632726057
40	https://www.immobiliare.it/annunci/98846848/	1	1	3	19/10/2022	corso Monte Cucco 121	45,063804	7,631091
41	https://www.immobiliare.it/annunci/96313406/	1	1	2	18/10/2022	via Monte Ortigara 41	45,06737339	7,631285158
42	https://www.immobiliare.it/annunci/98170122/	1	1	3	18/10/2022	via Monte Ortigara 3	45,0661972	7,6364174
43	https://www.immobiliare.it/annunci/98824396/	1	1	1	19/10/2022	corso Vittorio Emanuele II 235	45,0747017	7,644682303
44	https://www.immobiliare.it/annunci/98929208/	1	1	3	19/10/2022	corso Monte Cucco 87	45,06688646	7,632429603
45	https://www.immobiliare.it/annunci/95772978/	1	1	2	18/10/2022	corso Monte Cucco 120	45,06472252	7,630628927
46	https://www.immobiliare.it/annunci/97582496/	1	1	1	18/10/2022	via Valdieri 21	45,0701414	7,6520844
47	https://www.immobiliare.it/annunci/94902650/	1	1	1	15/10/2022	via Oulx 28	45.072800	7,63524
48	https://www.immobiliare.it/annunci/98895412/	1	1	1	16/10/2022	via Aurelio Saffi 23	45,07336	7,65168
49	https://www.immobiliare.it/annunci/98822824/	1	1	1	13/10/2022	corso Monte Grappa 56	45,07915	7,63763
50	https://www.immobiliare.it/annunci/99309472/	1	1	2	9/11/2022	via Vasile Alecsandri 5	45,06972	7,62986

51	https://www.immobiliare.it/annunci/98895882/	1	1	1	16/10/2022	via Mocchie 6	45,07427041	7,65094237
52	https://www.immobiliare.it/annunci/98906278/	1	1	3	17/10/2022	via Monte Ortigara 8	45,06648445	7,636143962
53	https://www.immobiliare.it/annunci/98873072/	1	1	2	17/10/2022	via S. Antonino 48	45,07391085	7,632228243
54	https://www.immobiliare.it/annunci/99324850/	1	1	1	17/11/2022	corso Monte Cucco 23	45,07302017	7,6349181
55	https://www.immobiliare.it/annunci/98922964/	1	1	3	18/10/2022	Via Cardinale Maurilio Fossati 5	45,06935931	7,634778753
56	https://www.immobiliare.it/annunci/99439326/	1	1	2	14/11/2022	corso Bernardino Telesio 14	45,07605418	7,625355644
57	https://www.immobiliare.it/annunci/94727452/	1	1	3	18/10/2022	corso Monte Cucco 107	45,06526172	7,631703494
58	https://www.immobiliare.it/annunci/98858106/	1	1	1	18/10/2022	via Giacomo Medici 29/A	45,0775873	7,6518689
59	https://www.immobiliare.it/annunci/95077534/	1	1	1	18/10/2022	via Zumaglia 17	45,0777213	7,6435972
60	https://www.immobiliare.it/annunci/99439646/	1	1	3	17/11/2022	via Monte Ortigara 8	45,06648445	7,636143962
61	https://www.immobiliare.it/annunci/89766629/	1	1	1	14/10/2022	via Caprie 20	45,073906	7,650383
62	https://www.immobiliare.it/annunci/95099828/	1	1	1	14/10/2022	via Borgone 2	45,07484432	7,636427027
63	https://www.immobiliare.it/annunci/98740082/	1	1	1	14/10/2022	via Rubiana 47	45,0717314	7,6393696
64	https://www.immobiliare.it/annunci/93815650/	1	1	1	14/10/2022	via Freidour 14	45,07451296	7,641201188
65	https://www.immobiliare.it/annunci/98393826/	1	1	1	14/10/2022	via Borgone 33	45,0719188	7,6368325
66	https://www.immobiliare.it/annunci/93309016/	1	1	1	14/10/2022	via Borgone 2	45,07484432	7,636427027
67	https://www.immobiliare.it/annunci/54309906/	1	1	1	14/10/2022	via Beaulard 72	45,0701606	7,6379757
68	https://www.immobiliare.it/annunci/92315756/	1	1	1	14/10/2022	via Borgone 2	45,07484432	7,636427027
69	https://www.immobiliare.it/annunci/98874562/	1	1	2	14/10/2022	via Monginevro 172/3	45,0650051	7,6296683
70	https://www.immobiliare.it/annunci/99513862/	1	1	1	17/11/2022	via Bardonecchia 93	45,07214675	7,636140102
71	https://www.immobiliare.it/annunci/98159604/	1	1	3	15/10/2022	via Monte Cristallo 12	45,0616016	7,6304653
72	https://www.immobiliare.it/annunci/98883226/	1	1	1	15/10/2022	via Frejus 6	45,0712668	7,6527804
73	https://www.immobiliare.it/annunci/98357392/	1	1	3	13/10/2022	via Lorenzo Delleani 8	45,06735282	7,636354591
74	https://www.immobiliare.it/annunci/98444686/	1	1	2	13/10/2022	via Tofane 44 A	45,06680187	7,630909862
75	https://www.immobiliare.it/annunci/98481702/	1	1	1	13/10/2022	via Bardonecchia 68	45,0725427	7,6401853
76	https://www.immobiliare.it/annunci/96825358/	1	1	3	13/10/2022	via Matilde Serao 3	45,0654377	7,6340719
77	https://www.immobiliare.it/annunci/98173448/	1	1	1	13/10/2022	via Enrico Cialdini 26	45,074614	7,6516447
78	https://www.immobiliare.it/annunci/93567132/	1	1	1	13/10/2022	via Enrico Cialdini 47	45,0751606	7,6492563
79	https://www.immobiliare.it/annunci/96826560/	1	1	3	13/10/2022	Via Cardinale Maurilio Fossati 26	45,0675383	7,633419
80	https://www.immobiliare.it/annunci/95715596/	1	1	2	13/10/2022	largo Bardonecchia 180	45,0721969	7,6251688
81	https://www.immobiliare.it/annunci/97298386/	1	1	1	13/10/2022	via Piedicavallo 20	45,0774693	7,642119
82	https://www.immobiliare.it/annunci/98863092/	1	1	1	14/10/2022	largo Francia 111	45,075482	7,6491176
83	https://www.immobiliare.it/annunci/97465454/	1	1	2	13/10/2022	corso Monte Cucco 62	45,0701378	7,63295
84	https://www.immobiliare.it/annunci/95768072/	1	1	3	13/10/2022	corso Monte Cucco 59	45,0696818	7,6336401
85	https://www.immobiliare.it/annunci/98387124/	1	1	2	13/10/2022	via Valgioie 83	45,0767496	7,626538
86	https://www.immobiliare.it/annunci/97356090/	1	1	2	13/10/2022	largo Bardonecchia 180	45,0721969	7,6251688
87	https://www.immobiliare.it/annunci/98929962/	1	1	2	26/10/2022	corso Peschiera 325	45,0729905	7,6273623
88	https://www.immobiliare.it/annunci/93464864/	1	1	2	26/10/2022	via Bardonecchia 200	45,0720004	7,6237197
89	https://www.immobiliare.it/annunci/96024678/	1	1	1	26/10/2022	via Frassineto 37	45,0689029	7,6403798
90	https://www.immobiliare.it/annunci/95725970/	1	1	1	26/10/2022	corso Vittorio Emanuele II 184	45,073409	7,649822
91	https://www.immobiliare.it/annunci/94626212/	1	1	3	26/10/2022	via Giovanni Fattori 4	45,0681213	7,6373022
92	https://www.immobiliare.it/annunci/98912110/	1	1	2	26/10/2022	via S. Antonino 30	45,073872	7,63372
93	https://www.immobiliare.it/annunci/98634086/	1	1	2	26/10/2022	via Sarre 3	45,07417	7,62963
94	https://www.immobiliare.it/annunci/94338258/	1	1	2	16/11/2022	via Luigi Ferdinando Marsigli 117	45,0645568	7,6268477
95	https://www.immobiliare.it/annunci/98953264/	1	1	2	25/10/2022	corso Monte Cucco 118	45,06492689	7,630699372
96	https://www.immobiliare.it/annunci/98074732/	1	1	1	25/10/2022	corso Trapani 48	45,0719256	7,6402781
97	https://www.immobiliare.it/annunci/98856204/	1	1	1	25/10/2022	via Bardonecchia 103	45,07215093	7,635112701
98	https://www.immobiliare.it/annunci/92280220/	1	1	2	25/10/2022	via Stelvio 67	45,06630244	7,626319076
99	https://www.immobiliare.it/annunci/95925330/	1	1	1	18/11/2022	via Frejus 156	45,0698926	7,6376481
100	https://www.immobiliare.it/annunci/91512216/	1	1	1	25/10/2022	corso Peschiera 284	45,070709	7,634507

Figure 177 Data sample for location. (Source: Elaboration by the Author).

IDAP	BUILDING_TYPOLOGY	FACADE_TYPOLOGY	PRICE	SURFACE	PRICE/SQM	FLOOR_NUMBER	TOTAL_FLOOR	LAST_FLOOR	FLOORS	CONSTRUCTION_YEAR	CATEGORY	CONSERVATION	ELEVATOR	GREEN	VIEW_OUT
1	3	1	109000	75	1453,333333	1	5	0	2	1	2	2	0	0	1
2	3	1	125000	71	1760,56338	2	8	0	2	2	2	1	1	0	1
3	2	4	148000	48	3083,333333	1	3	0	2	3	3	3	1	1	2
4	2	1	88000	60	1466,666667	2	3	1	3	2	2	3	0	0	1
5	3	3	105000	64	1640,625	1	10	0	2	3	3	2	1	1	2
6	2	1	120000	75	1600	1	2	1	3	2	2	2	0	1	2
7	3	3	318000	160	1987,5	7	9	0	2	2	3	1	1	1	3
8	3	1	58000	50	1160	0	6	0	1	2	2	1	0	0	1
9	3	1	89000	50	1780	3	6	0	2	2	2	3	1	0	2
10	3	4	199000	80	2487,5	1	9	0	2	2	3	2	1	1	2
11	3	1	199000	101	1970,29703	1	10	0	2	3	2	3	1	0	2
12	3	1	264000	125	2112	2	7	0	2	3	2	2	1	0	2
13	3	3	335000	120	2791,666667	9	10	1	3	3	2	3	1	1	3
14	3	3	399000	150	2660	6	10	0	2	3	3	2	1	0	3
15	3	4	309000	150	2060	9	10	1	3	3	2	2	1	0	3
16	3	1	150000	107	1401,869159	2	8	0	2	3	2	1	1	0	2
17	1	4	109000	70	1557,142857	0	2	0	1	2	2	3	0	0	1
18	1	4	105000	70	1500	1	2	1	3	2	2	3	0	0	1
19	3	3	158000	70	2257,142857	1	6	0	2	3	2	3	1	0	1
20	3	3	219000	85	2576,470588	9	10	1	3	3	2	3	1	0	3
21	3	2	348000	123	2829,268293	2	4	0	2	1	1	3	1	0	1
22	3	3	248000	115	2156,521739	7	9	0	2	2	2	2	1	0	3
23	3	3	145000	80	1812,5	6	7	1	3	3	2	2	1	0	3
24	1	2	99000	65	1523,076923	0	2	0	1	1	0	3	0	1	2
25	3	1	165000	86	1918,604651	2	5	0	2	2	2	2	1	1	2
26	3	3	345000	173	1994,219653	5	10	0	2	3	3	2	1	1	3
27	3	1	140000	78	1794,871795	3	5	0	2	2	3	3	0	0	1
28	3	3	149000	70	2128,571429	7	9	0	2	3	2	2	1	1	3
29	3	3	278000	106	2622,641509	7	10	0	2	3	2	3	1	0	3
30	2	1	138000	89	1550,561798	1	3	0	2	2	2	3	0	0	2
31	3	1	169000	90	1877,777778	4	6	0	2	3	2	2	1	0	1
32	3	1	95000	60	1583,333333	4	7	0	2	3	2	3	1	0	3
33	3	1	197000	74	2662,162162	5	6	1	3	3	3	3	1	0	3
34	3	3	132000	72	1833,333333	6	10	0	2	3	2	2	1	0	3
35	3	3	200000	132	1515,151515	2	8	0	2	3	3	2	1	0	3
36	3	3	179000	75	2386,666667	0	8	0	1	3	3	3	1	0	1
37	3	3	52000	25	2080	6	6	1	3	3	3	2	1	0	3
38	3	1	88000	72	1222,222222	1	5	0	2	1	0	2	0	0	1
39	3	4	198000	110	1800	9	10	1	3	4	3	3	1	1	3
40	3	3	142000	67	2119,402985	7	10	0	2	3	3	3	1	1	3
41	3	1	319000	160	1993,75	6	11	0	2	3	3	2	1	1	3
42	3	4	175000	105	1666,666667	0	6	0	1	2	2	3	1	0	1
43	3	4	275000	135	2037,037037	6	9	0	2	2	3	2	1	1	3
44	3	3	400000	176	2272,727273	6	10	0	2	3	3	2	1	1	3
45	3	3	99000	60	1650	7	10	0	2	3	2	2	1	1	3
46	3	1	285000	150	1900	1	6	0	2	3	3	2	1	0	1
47	3	1	49000	55	890,9090909	3	4	1	3	3	2	2	0	0	2
48	2	1	165000	80	2062,5	0	6	0	1	3	3	1	1	0	1
49	3	1	250000	105	2380,952381	8	9	1	3	3	1	2	1	0	3
50	3	3	298000	105	2838,095238	2	7	0	2	5	3	3	1	0	3

51	3	3	137000	45	3044,444444	0	7	0	1	3	0	3	1	0	1
52	3	3	149000	70	2128,571429	1	7	0	2	3	2	3	1	0	1
53	3	3	200000	76	2631,578947	1	6	0	2	3	3	2	1	1	2
54	3	1	149000	82	1817,073171	2	10	0	2	3	0	2	1	0	2
55	3	3	395000	140	2821,428571	8	10	0	2	3	3	3	1	0	3
56	3	4	189000	90	2100	8	10	1	3	2	3	2	1	1	3
57	3	1	119000	63	1888,888889	1	6	0	2	3	0	2	1	0	2
58	3	2	159000	80	1987,5	1	5	0	2	2	2	3	1	1	2
59	3	1	110000	70	1571,428571	3	5	0	2	2	2	2	1	0	2
60	3	3	265000	110	2409,090909	5	7	0	2	3	3	2	1	0	2
61	3	3	125000	44	2840,909091	1	6	0	2	5	3	3	1	1	2
62	3	1	93000	57	1631,578947	0	6	0	1	2	2	3	1	0	1
63	3	3	130000	81	1604,938272	1	6	0	2	3	2	2	1	0	1
64	3	3	157000	77	2038,961039	0	6	0	1	3	2	3	1	0	1
65	3	1	90000	60	1500	0	6	0	1	3	2	2	1	0	1
66	3	1	120000	53	2264,150943	3	6	0	2	2	2	3	1	0	3
67	3	1	74000	80	925	5	6	1	3	1	2	2	0	0	3
68	3	1	125000	53	2358,490566	4	6	0	2	2	2	3	1	0	3
69	3	1	155000	85	1823,529412	2	5	0	2	2	2	3	0	0	2
70	3	4	165000	99	1666,666667	2	8	0	2	3	3	2	1	1	2
71	3	1	228000	100	2280	4	6	0	2	3	2	2	1	0	3
72	3	4	419000	135	3103,703704	7	8	1	3	3	2	3	1	1	3
73	3	3	370000	177	2090,39548	4	6	0	2	3	3	2	1	1	3
74	3	1	350000	165	2121,212121	3	11	0	2	3	2	2	1	1	2
75	3	4	165000	90	1833,333333	4	7	0	2	2	2	2	1	0	2
76	3	3	229000	85	2694,117647	2	6	0	2	5	3	3	1	0	2
77	3	3	289000	150	1926,666667	0	9	0	1	2	3	3	1	0	1
78	3	2	165000	60	2750	0	5	0	1	2	3	3	1	0	1
79	3	3	165000	98	1683,673469	1	8	0	2	3	3	2	1	1	1
80	3	3	168000	85	1976,470588	6	9	0	2	3	2	2	1	1	3
81	3	2	139000	80	1737,5	5	5	1	3	1	1	2	1	0	3
82	3	2	149000	70	2128,571429	4	5	1	3	1	0	2	1	0	3
83	3	4	239000	110	2172,727273	8	10	0	2	3	3	2	1	1	2
84	3	3	350000	160	2187,5	3	11	0	2	3	3	3	1	1	2
85	3	1	120000	160	750	9	9	1	3	2	3	1	1	0	3
86	3	3	125000	65	1923,076923	6	9	0	2	3	2	3	1	1	3
87	3	3	175000	90	1944,444444	1	10	0	2	3	3	1	1	0	2
88	3	1	77000	60	1283,333333	3	4	1	3	2	2	2	0	0	3
89	1	2	135000	90	1500	3	5	0	2	1	2	2	0	0	2
90	3	3	279000	110	2536,363636	8	10	0	2	3	3	2	1	0	3
91	3	3	339000	137	2474,452555	7	11	0	2	3	3	3	1	1	3
92	3	3	138000	70	1971,428571	1	6	0	2	3	0	2	1	0	2
93	3	1	79000	52	1519,230769	2	6	0	2	3	2	2	0	0	1
94	3	1	49000	50	980	4	6	0	2	2	1	3	0	0	2
95	3	4	135000	60	2250	8	10	0	2	3	2	2	1	1	3
96	3	3	375000	140	2678,571429	2	10	0	2	3	3	3	1	0	1
97	3	4	200000	106	1886,792453	5	8	0	2	3	3	2	1	1	3
98	3	3	259000	145	1786,206897	3	8	0	2	3	3	2	1	1	2
99	3	2	65000	70	928,5714286	4	5	1	3	1	2	3	0	0	3
100	3	3	225000	125	1800	1	10	0	2	3	3	1	1	1	2

Figure 178 Data sample for context.
(Source: Elaboration by the Author).

IDAP	NOISE_daily	NOISE_night	NOISE_average
1	2	2	2
2	1	1	1
3	2	2	2
4	1	1	1
5	2	2	2
6	2	2	1
7	2	2	1
8	1	2	1
9	2	2	2
10	1	1	1
11	2	2	1
12	2	2	2
13	1	1	1
14	2	2	1
15	3	3	3
16	1	1	1
17	3	3	3
18	3	3	3
19	1	2	1
20	2	2	1
21	1	2	1
22	1	1	1
23	1	1	1
24	3	3	3
25	2	2	2
26	2	2	2
27	2	2	1
28	1	1	1
29	1	1	1
30	1	2	1
31	1	2	1
32	1	2	1
33	2	2	1
34	1	1	1
35	1	1	1
36	1	2	1
37	3	2	3
38	2	2	1
39	1	2	1
40	1	2	1
41	2	2	2
42	2	2	1
43	1	1	1
44	1	2	1
45	1	2	1
46	1	2	1
47	1	2	1
48	2	2	2
49	1	2	1
50	2	3	2

IDAP	n_ROOMS	BATHROOMS	KITCHEN	BALCONIES	BALCONIES10	TERRACES	TERRACES10	BALCONY_TERRACE
1	3	1	1	2	1	0	0	1
2	3	1	1	2	1	0	0	1
3	2	1	1	1	1	0	0	1
4	2	1	2	2	1	0	0	1
5	2	1	2	2	1	0	0	1
6	3	1	4	2	1	0	0	1
7	5	2	3	3	1	0	0	1
8	2	1	1	1	1	0	0	1
9	2	1	1	2	1	0	0	1
10	3	1	2	2	1	1	1	1
11	4	1	3	3	1	0	0	1
12	4	1	2	2	1	1	1	1
13	4	2	3	0	0	2	1	1
14	5	2	3	2	1	1	1	1
15	5	2	4	2	1	0	0	1
16	4	2	4	2	1	0	0	1
17	3	1	4	1	1	0	0	1
18	3	1	1	1	1	0	0	1
19	3	1	3	2	1	0	0	1
20	3	1	3	2	1	0	0	1
21	4	2	3	2	1	0	0	1
22	4	1	3	4	1	0	0	1
23	3	1	2	2	1	0	0	1
24	2	1	1	0	0	0	0	0
25	3	1	4	1	1	1	1	1
26	5	2	3	0	0	2	1	1
27	3	1	3	1	1	1	1	1
28	3	1	3	2	1	0	0	1
29	4	1	3	1	1	0	0	1
30	3	1	2	3	1	0	0	1
31	3	1	2	0	0	2	1	1
32	2	1	2	1	1	0	0	1
33	3	1	1	2	1	1	1	1
34	3	1	3	1	1	0	0	1
35	4	2	4	1	1	1	1	1
36	3	1	4	1	1	0	0	1
37	1	1	1	0	0	0	0	0
38	3	1	3	2	1	0	0	1
39	4	2	2	2	1	0	0	1
40	2	1	3	2	1	0	0	1
41	6	2	3	0	0	3	1	1
42	4	1	4	0	0	1	1	1
43	4	2	2	1	1	1	1	1
44	6	3	3	2	1	0	0	1
45	2	1	2	2	1	0	0	1
46	5	2	2	4	1	0	0	1
47	2	1	2	1	1	0	0	1
48	3	2	4	0	0	0	0	0
49	3	1	3	3	1	0	0	1
50	4	2	3	0	0	2	1	1

51	2	2	2
52	2	2	2
53	2	2	1
54	1	2	1
55	2	2	2
56	1	2	1
57	1	2	1
58	2	2	2
59	2	2	1
60	2	2	2
61	2	2	2
62	1	2	1
63	2	2	2
64	2	2	1
65	2	2	2
66	1	2	1
67	2	2	2
68	1	2	1
69	2	2	1
70	2	2	1
71	2	2	1
72	2	2	2
73	2	2	2
74	2	2	1
75	1	2	1
76	2	2	1
77	1	1	1
78	1	2	1
79	1	2	1
80	1	2	1
81	2	2	2
82	1	2	1
83	1	2	1
84	1	2	1
85	2	2	2
86	1	2	1
87	1	1	1
88	1	2	1
89	1	2	1
90	1	1	1
91	2	3	2
92	2	2	1
93	2	2	2
94	1	2	1
95	1	2	1
96	1	1	1
97	2	2	1
98	3	3	2
99	1	2	1
100	1	1	1

51	2	1	1	1	1	0	0	1
52	2	1	1	1	1	0	0	1
53	2	1	3	1	1	0	0	1
54	3	1	2	1	1	1	1	1
55	5	2	3	2	1	0	0	1
56	3	1	1	1	1	1	1	1
57	2	1	2	1	1	0	0	1
58	3	1	3	1	1	0	0	1
59	3	1	1	2	1	0	0	1
60	4	1	3	2	1	0	0	1
61	1	1	1	2	1	0	0	1
62	2	1	1	1	1	0	0	1
63	3	1	2	2	1	0	0	1
64	3	1	1	1	1	0	0	1
65	2	1	2	0	0	1	1	1
66	2	1	1	1	1	0	0	1
67	3	1	4	2	1	0	0	1
68	2	1	1	1	1	0	0	1
69	3	1	4	1	1	1	1	1
70	3	1	2	2	1	0	0	1
71	4	1	2	2	1	1	1	1
72	5	2	3	3	1	0	0	1
73	6	2	2	0	0	2	1	1
74	5	2	4	0	0	3	1	1
75	3	1	2	1	1	2	1	1
76	4	1	4	0	0	2	1	1
77	6	2	4	1	1	0	0	1
78	2	1	4	1	1	0	0	1
79	3	1	2	1	1	0	0	1
80	3	1	2	1	1	1	1	1
81	3	2	1	5	1	0	0	1
82	3	1	4	5	1	0	0	1
83	4	1	2	2	1	1	1	1
84	4	2	4	2	1	0	0	1
85	4	2	1	0	0	1	1	1
86	2	1	2	2	1	0	0	1
87	3	1	2	2	1	0	0	1
88	3	1	4	2	1	0	0	1
89	4	1	4	3	1	0	0	1
90	4	1	3	2	1	0	0	1
91	4	2	3	1	1	1	1	1
92	3	1	2	2	1	0	0	1
93	2	1	1	1	1	1	1	1
94	2	1	2	1	1	0	0	1
95	2	1	2	2	1	0	0	1
96	4	2	1	1	1	0	0	1
97	3	1	2	2	1	0	0	1
98	4	2	3	1	1	1	1	1
99	3	1	4	2	1	0	0	1
100	4	2	3	0	0	2	1	1

Figure 179-180 Data sample for noise pollution and indoor configuration. (Source: Elaboration by the Author).

IDAP	ORIENTATION	VIEWS	GLAZING	FRAME
1	2	2	2	3
2	4	1	1	1
3	1	2	2	1
4	2	2	2	3
5	3	2	2	3
6	1	2	1	1
7	2	3	2	1
8	4	2	1	1
9	3	2	2	2
10	2	2	1	1
11	2	2	1	1
12	4	2	1	1
13	3	2	1	1
14	3	2	1	1
15	2	3	1	1
16	4	2	1	1
17	1	2	2	3
18	1	2	2	3
19	1	2	2	3
20	3	2	2	3
21	1	2	2	3
22	2	2	2	1
23	2	2	1	1
24	2	1	1	1
25	3	2	2	2
26	3	2	1	1
27	4	2	1	1
28	2	2	2	1
29	1	2	2	3
30	4	2	2	3
31	1	2	2	1
32	4	1	2	3
33	4	2	2	3
34	4	2	2	1
35	1	3	2	1
36	3	2	1	1
37	4	1	2	1
38	2	2	1	1
39	4	3	2	3
40	4	2	1	1
41	4	3	2	3
42	3	2	1	1
43	3	2	1	1
44	4	3	1	1
45	4	2	2	1
46	1	3	2	1
47	2	2	1	1
48	3	2	1	1
49	4	3	1	1
50	3	2	2	1

51	1	2	1	1
52	3	2	1	1
53	4	1	2	1
54	4	2	2	2
55	4	3	2	3
56	3	2	2	3
57	3	1	1	1
58	2	2	2	1
59	1	2	2	3
60	3	2	1	1
61	1	2	2	1
62	1	2	2	3
63	3	2	1	1
64	2	2	2	3
65	1	2	2	3
66	1	1	2	3
67	1	2	1	1
68	1	1	2	3
69	4	2	2	1
70	2	2	1	1
71	3	3	1	1
72	3	3	2	1
73	3	2	1	1
74	3	3	2	1
75	2	2	2	1
76	4	3	2	1
77	3	2	1	1
78	3	2	1	1
79	3	2	1	1
80	3	2	2	3
81	1	2	2	3
82	1	2	2	2
83	4	2	1	1
84	4	2	1	1
85	2	2	2	3
86	4	2	1	1
87	3	2	1	1
88	2	2	1	3
89	3	3	2	2
90	3	2	1	2
91	3	3	2	1
92	2	2	1	1
93	2	2	2	3
94	4	1	2	3
95	4	2	2	2
96	4	3	2	3
97	2	3	2	1
98	4	3	2	3
99	4	2	2	3
100	3	3	1	1

Figure 181 Data sample for daylight.
(Source: Elaboration by the Author).

IDAP	WFR	WFRallflat	WFRutile	Dfmflat	Dfmutile	medianDF	sDAutile	ASEutile	UDI.f	UDI.a	UDI.e	avg_lux	blinds closed	SF%
1	1	1	1	1	1	1	1	0	2	2	1	1	2	2
2	1	2	2	2	2	1	1	1	2	3	1	3	1	2
3	1	1	2	1	1	1	1	0	2	2	1	1	3	1
4	1	1	1	1	1	1	1	0	2	2	1	2	3	2
5	1	2	2	1	2	1	1	0	2	2	1	2	3	1
6	1	1	2	2	2	1	1	0	3	3	1	2	2	1
7	1	1	2	2	2	1	3	0	3	4	1	3	3	2
8	0	0	0	1	1	1	1	0	2	1	1	1	3	1
9	1	1	2	1	1	1	1	0	2	3	1	2	3	1
10	1	2	2	2	2	1	2	0	3	3	0	4	2	1
11	1	1	1	2	2	1	1	0	2	2	1	2	3	1
12	1	2	2	2	2	1	1	0	2	2	1	3	2	2
13	1	1	2	2	2	1	2	1	2	3	1	3	3	1
14	1	2	2	3	3	2	3	1	3	4	0	4	2	1
15	1	2	2	2	2	2	3	0	3	4	1	3	3	1
16	1	1	2	1	1	1	1	0	2	2	1	2	3	1
17	1	2	1	1	1	1	1	0	1	1	1	1	3	1
18	1	1	1	2	2	1	1	0	2	2	1	2	3	1
19	1	1	2	1	1	1	1	0	1	1	1	1	3	1
20	1	1	1	2	2	1	1	1	2	2	1	2	3	2
21	0	0	0	1	1	1	1	0	1	1	1	1	3	2
22	1	1	1	1	1	1	1	0	2	2	1	2	2	2
23	1	1	1	2	2	1	1	0	2	3	1	2	2	1
24	0	0	0	1	2	1	1	0	1	1	1	1	3	0
25	1	1	2	2	2	1	1	0	3	3	1	3	2	2
26	1	1	2	1	2	1	1	0	2	3	1	2	3	1
27	1	1	2	2	2	1	1	0	2	3	1	3	3	1
28	1	1	2	1	2	1	1	0	3	3	1	2	2	2
29	1	2	2	3	3	2	3	1	3	4	0	4	1	2
30	1	2	2	2	2	1	1	0	2	2	1	2	2	1
31	1	1	2	1	2	1	1	0	3	3	1	2	2	1
32	1	1	2	2	2	1	1	0	2	3	1	2	2	2
33	1	1	2	1	1	1	1	0	2	2	1	1	2	1
34	1	1	2	2	2	1	1	1	3	3	1	3	2	2
35	1	1	1	1	1	1	1	0	2	2	1	1	3	1
36	1	2	2	1	1	1	1	0	2	2	1	1	3	1
37	0	0	0	3	3	1	1	1	2	2	0	4	1	2
38	1	1	1	1	1	1	1	0	2	2	1	2	3	1
39	1	2	2	2	2	2	2	1	3	3	1	3	2	2
40	1	2	2	1	2	1	1	0	3	3	1	2	3	1
41	1	2	2	2	2	1	2	0	3	3	1	3	2	2
42	1	2	2	3	2	1	1	0	2	2	1	3	1	2
43	1	2	2	2	3	2	3	0	3	4	1	4	3	1
44	1	1	2	2	3	1	2	0	3	3	0	3	2	2
45	1	2	2	2	2	1	1	0	3	3	1	2	2	2
46	1	1	2	1	2	1	1	0	2	3	1	2	3	1
47	1	1	0	2	2	1	1	1	2	3	0	2	2	2
48	1	1	1	1	2	1	1	0	2	2	1	2	3	1
49	1	2	2	3	4	3	4	0	3	4	0	4	3	2
50	1	2	2	2	2	1	1	0	3	3	1	2	3	1

51	1	1	2	1	1	1	1	0	2	2	1	2	3	0
52	1	1	2	1	1	1	1	0	2	2	1	1	3	1
53	1	1	1	2	2	1	1	1	2	3	1	3	1	2
54	1	1	1	1	1	1	1	0	2	2	1	1	2	1
55	1	1	2	2	2	2	1	0	3	3	1	2	3	2
56	1	2	2	2	2	1	2	1	3	3	1	3	2	1
57	1	2	2	2	2	1	2	1	3	3	0	3	2	1
58	1	1	2	2	2	1	1	0	2	3	1	2	3	2
59	1	1	2	1	1	1	1	0	2	2	1	1	2	1
60	1	1	1	2	2	1	1	0	2	3	1	3	2	1
61	1	2	2	2	2	2	2	0	3	3	1	3	2	1
62	1	1	2	2	2	1	1	0	2	3	1	2	2	1
63	1	1	2	1	1	1	1	0	2	2	1	1	3	1
64	1	1	1	1	1	1	1	0	2	2	1	2	2	1
65	1	1	2	1	1	1	1	0	2	2	1	1	3	1
66	1	2	2	2	2	1	2	1	3	3	1	3	2	2
67	1	1	1	2	2	1	1	0	3	3	1	2	2	1
68	1	2	2	2	2	1	2	1	3	3	1	3	2	2
69	1	1	2	2	2	1	1	0	2	3	1	2	2	2
70	1	2	2	2	2	1	2	0	3	3	1	3	3	1
71	1	2	2	2	2	1	2	1	3	3	0	3	2	1
72	1	1	2	2	2	1	1	0	3	3	1	2	3	2
73	1	1	2	2	2	1	1	0	3	3	1	2	3	1
74	1	2	2	2	2	1	2	0	3	3	1	3	2	1
75	1	1	1	1	1	1	1	0	2	2	1	2	2	1
76	1	1	1	1	1	1	1	0	2	2	1	1	3	1
77	0	0	0	1	1	1	1	0	1	1	1	1	2	1
78	0	0	0	1	1	1	1	0	2	2	1	2	3	1
79	1	1	1	2	2	1	2	1	2	3	0	3	2	1
80	1	2	2	2	2	2	2	0	3	3	1	4	3	2
81	1	2	2	2	2	1	1	0	2	2	1	2	3	2
82	1	2	2	3	3	2	3	1	3	4	0	4	2	2
83	1	1	1	2	2	1	1	0	3	3	1	3	2	2
84	1	1	2	2	2	1	1	0	2	3	1	2	3	1
85	0	0	0	3	3	2	2	0	3	3	1	4	2	2
86	1	2	2	2	3	2	4	0	3	4	0	4	2	2
87	1	2	2	2	2	1	1	0	3	3	1	2	3	1
88	1	2	2	2	2	2	3	1	3	4	1	4	2	2
89	1	2	2	2	2	1	2	0	3	3	1	2	3	2
90	1	1	1	2	2	1	1	1	2	2	1	2	2	2
91	1	1	2	2	2	1	1	0	2	2	1	2	2	1
92	1	1	2	1	2	1	1	0	3	2	1	2	3	1
93	1	1	1	1	1	1	1	0	2	1	1	1	3	1
94	1	2	2	2	3	1	1	1	3	3	0	3	2	2
95	1	2	2	2	2	1	1	0	3	3	1	2	2	2
96	1	1	2	2	2	1	1	0	2	1	1	1	3	2
97	1	1	2	2	2	1	2	0	3	3	1	3	2	2
98	1	2	2	2	2	1	2	0	3	3	1	3	3	1
99	1	2	2	2	2	1	1	0	3	3	1	2	3	1
100	1	1	1	2	2	1	1	0	3	3	1	1	2	1

Figure 182 Data sample for daylight simulations (considering vegetation). (Source: Elaboration by the Author).

IDAP	Dfmflat*	Dfmutile*	medianDF*	SDAutile*	ASEutile*	UDI.f*	UDI.a*	UDI.e*	avg_lux*	blindsclosed*	SF%*
1	1	1	1	1	0	2	2	1	1	2	2
2	1	1	1	1	0	2	2	1	2	2	1
3	1	1	1	1	0	2	2	1	1	3	1
4	1	1	1	1	0	2	2	1	2	3	2
5	1	2	1	1	0	2	2	1	1	3	1
6	2	2	1	1	0	3	3	1	2	2	1
7	2	2	1	2	0	3	3	1	2	3	1
8	1	1	1	1	0	1	1	1	1	3	0
9	1	1	1	1	0	2	3	1	2	3	1
10	2	2	1	2	0	3	3	0	4	2	1
11	1	1	1	1	0	2	2	1	1	3	1
12	2	2	1	1	0	2	2	1	3	2	2
13	2	2	1	2	1	2	3	1	3	3	1
14	2	2	1	2	1	2	3	0	3	2	1
15	2	2	2	3	0	3	4	1	3	3	1
16	1	1	1	1	0	2	2	1	2	3	1
17	1	1	1	1	0	1	1	1	1	3	1
18	2	2	1	1	0	2	2	1	2	3	1
19	1	1	1	1	0	1	1	1	1	3	1
20	1	2	1	1	1	2	2	1	1	3	2
21	1	1	1	1	0	1	1	1	1	3	2
22	1	1	1	1	0	1	1	1	1	3	0
23	1	1	1	1	0	2	3	1	2	2	1
24	1	1	1	1	0	1	1	1	1	3	0
25	1	1	1	1	0	2	2	1	1	3	1
26	1	1	1	1	0	2	1	1	1	3	0
27	2	2	1	1	0	2	3	1	3	3	1
28	1	2	1	1	0	3	3	1	2	2	2
29	2	2	1	1	1	2	3	0	3	1	1
30	1	1	1	1	0	2	2	1	2	2	1
31	1	2	1	1	0	3	3	1	2	2	1
32	2	2	1	1	0	2	3	1	2	2	2
33	1	1	1	1	0	2	2	1	1	2	1
34	2	2	1	1	0	2	2	1	2	2	1
35	1	1	1	1	0	2	1	1	1	3	1
36	1	1	1	1	0	2	2	1	1	3	0
37	3	3	1	1	1	2	2	0	4	1	2
38	1	1	1	1	0	2	2	1	2	3	1
39	2	2	2	3	1	3	4	1	3	2	2
40	1	1	1	1	0	1	1	1	1	3	0
41	2	2	1	2	0	3	3	1	3	2	1
42	3	2	1	1	0	2	2	1	3	2	2
43	2	2	2	2	0	3	4	1	3	3	1
44	2	2	1	1	0	2	3	1	2	2	2
45	2	2	1	1	0	3	3	1	2	2	2
46	1	2	1	1	0	2	3	1	2	3	1
47	2	2	1	1	1	2	3	0	2	2	2
48	1	2	1	1	0	2	2	1	2	3	1
49	3	4	3	4	0	3	4	0	4	3	1
50	2	2	1	1	0	3	2	1	2	3	1

IDAP	APE	HEATING	SYSTEMH	SOURCEH	COOLING
1	1	1	1	1	0
2	1	1	1	0	0
3	3	2	3	1	0
4	2	1	1	1	1
5	1	1	1	2	0
6	2	2	1	1	1
7	1	1	1	2	0
8	1	1	1	1	0
9	1	1	1	1	1
10	2	1	1	1	0
11	1	1	1	1	1
12	1	1	3	1	1
13	1	1	1	0	1
14	1	1	1	1	0
15	1	1	2	1	0
16	1	1	1	1	0
17	1	2	1	1	1
18	1	2	1	1	1
19	1	1	1	1	0
20	2	1	1	1	1
21	1	1	1	0	1
22	1	1	1	1	1
23	1	1	1	1	0
24	1	2	1	1	0
25	2	1	1	1	0
26	3	1	1	1	0
27	3	1	1	2	1
28	1	1	1	1	0
29	1	1	1	1	1
30	1	1	1	0	0
31	2	1	1	2	1
32	1	1	1	1	0
33	1	1	1	3	0
34	1	1	1	1	1
35	1	1	1	1	0
36	2	1	0	0	0
37	1	1	1	1	1
38	1	1	1	0	0
39	1	1	1	1	1
40	1	1	1	2	0
41	3	1	1	1	0
42	1	1	1	1	0
43	1	1	2	1	0
44	1	1	1	3	0
45	1	1	1	1	0
46	2	1	1	1	0
47	1	1	1	1	0
48	2	1	3	1	0
49	1	1	1	1	0
50	2	2	1	1	1

51	1	1	1	1	0	2	2	1	2	3	0
52	1	1	1	1	0	2	2	1	1	3	1
53	2	2	1	1	1	2	3	1	3	1	2
54	1	1	1	1	0	1	1	1	1	3	1
55	2	2	1	1	0	3	3	1	2	2	2
56	2	2	1	2	1	3	3	1	3	2	1
57	2	2	1	2	1	3	3	0	3	2	1
58	2	2	1	1	0	2	3	1	2	3	2
59	1	1	1	1	0	2	2	1	1	2	1
60	2	2	1	1	0	2	3	1	2	2	1
61	2	2	1	1	0	3	3	1	3	2	1
62	2	2	1	1	0	2	3	1	2	2	1
63	1	2	1	1	0	2	2	1	1	3	1
64	1	1	1	1	0	2	2	1	2	3	1
65	1	1	1	1	0	2	2	1	1	3	1
66	2	2	1	2	1	3	3	1	3	2	2
67	2	2	1	1	0	3	3	1	2	2	1
68	2	2	2	2	1	3	3	1	3	2	2
69	2	2	1	1	0	2	3	1	2	2	2
70	2	2	1	2	0	3	3	1	3	3	1
71	2	2	1	2	1	3	3	0	3	2	1
72	2	2	1	1	0	3	3	1	2	3	2
73	2	2	1	1	0	3	3	1	2	3	1
74	2	2	1	2	0	3	3	1	3	2	1
75	1	1	1	1	0	2	2	1	1	2	1
76	1	1	1	1	0	2	2	1	1	3	1
77	1	1	1	1	0	1	2	1	1	2	1
78	1	1	1	1	0	2	2	1	2	3	1
79	2	2	1	2	1	2	3	0	3	2	1
80	2	2	2	2	0	3	3	1	4	3	2
81	2	2	1	1	0	2	2	1	2	3	2
82	3	3	2	3	1	3	4	1	4	2	2
83	2	2	1	1	0	3	3	1	3	2	1
84	2	2	1	1	0	2	2	1	2	3	1
85	3	3	2	2	0	3	3	1	3	2	2
86	2	3	2	3	0	3	4	1	3	2	2
87	1	1	1	1	0	1	1	1	1	3	1
88	2	2	2	3	1	3	4	1	4	2	2
89	2	2	1	2	0	3	3	1	2	3	2
90	2	2	1	1	1	2	2	1	2	2	2
91	2	2	1	1	0	2	2	1	2	2	1
92	1	2	1	1	0	2	2	1	2	3	1
93	1	1	1	1	0	2	2	1	1	3	1
94	2	2	1	1	0	2	2	1	2	3	1
95	2	2	1	1	0	3	3	1	2	2	2
96	1	2	1	1	0	1	1	1	1	3	1
97	2	2	1	2	0	3	3	1	3	2	2
98	2	2	1	2	0	3	3	1	3	3	1
99	2	2	1	1	0	3	3	1	2	3	1
100	1	1	1	1	0	2	2	1	1	3	1

51	1	1	0	0	0
52	3	1	1	1	0
53	3	2	1	3	1
54	1	1	1	2	1
55	2	1	1	1	1
56	1	1	2	1	0
57	1	1	0	0	0
58	1	2	1	1	0
59	1	1	1	1	0
60	1	1	2	0	0
61	3	2	1	1	0
62	1	1	1	1	1
63	2	1	1	1	0
64	2	2	2	1	0
65	1	1	1	1	0
66	2	1	1	1	0
67	2	1	1	3	1
68	1	1	1	1	1
69	2	1	1	1	0
70	1	1	1	3	0
71	1	1	1	1	1
72	1	1	1	0	1
73	2	1	1	1	0
74	1	1	1	2	0
75	1	1	1	2	0
76	2	2	1	1	1
77	1	1	1	1	0
78	2	1	1	1	0
79	1	1	1	2	0
80	1	1	1	2	0
81	1	2	1	1	0
82	1	2	1	1	0
83	1	1	1	2	0
84	1	1	1	1	1
85	2	2	1	1	1
86	1	1	1	2	0
87	2	1	0	0	1
88	1	2	1	1	0
89	2	2	1	3	0
90	1	1	1	3	1
91	1	1	2	1	0
92	1	1	1	1	0
93	1	1	1	1	1
94	1	1	1	1	1
95	2	1	1	2	0
96	2	1	2	1	1
97	1	1	1	2	0
98	2	1	1	2	0
99	1	1	1	1	0
100	1	1	1	2	0

Figure 183 (left) Data sample for daylight simulations (excluding vegetation). (Source: Elaboration by the Author).

Figure 184 *(right)* Data sample for energy efficiency. (Source: Elaboration by the Author).

List of Images

Glossary

APE: Attestato di Prestazione Energetica is the Energy Performance Building Certificate indicating from energy classes A4 to G the energy performance of a building.

ASE: Annual Sunlight Exposure ($ASE_{1000,250h}$) (%) measures if 1000 lux are observed in a space for at least 250 hours per year due to radiation only (all reflections being excluded).

Average Daylight Factor (DF_m) should always be higher than 3% in residential units in Turin and is a static result obtained with information about window geometry and glazing transmittance, the room surface, the light reflection indoor, and the outdoor obstructions, without considering the climate of the setting under consideration.

Average Illuminance (lux) provides the average illuminance level during the occupied time (8 am - 6 pm), which minimum recommendation levels depend on the function of each space, from the circulation (100 lux), to regular usage in working and education environments (300-500 lux), up to more specific functions such as drawing-sewing (750 lux).

Daylight is the quantity of natural light entering a space, it is dynamic, and creates a stimulating and productive environment, improving the general well-being of people.

Daylighting is the success of a *proper* daylight provision in the architecture field, providing visual, and thermal comfort and improving energy efficiency.

Energy Performance of a building is the total amount of energy needed by the HVAC systems (heating, ventilation, air conditioning, hot water, and lighting)[190]. The objective of the EPBD Directives is to increase the usage of renewable resources for achieving zero-emissions buildings.

Implicit Marginal Price is the (positive or negative) monetary value found for each of the independent variables resulting in a Multiple Regression model, which, when summed, constitutes the dependent variable.

Glare is visual discomfort due to the brightness contrast and excessive luminous intensity in a space, can be defined as disabling or discomfort glare. The first reduces the detail's perception, the latter is a disturbing feeling[191].

[190] *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Official Journal of the European Union, L 153/13, Strasbourg.

[191] M.C. Torricelli, Sala M., Secchi S., (1995), *Daylight: La Luce del Giorno*, Alinea editrice, pp. 107-108.

MRA: Multiple Regression Analysis is a synthetic estimate using a pluri-parametric procedure with one dependent variable and multiple independent variables.

Nearly zero-energy building A nearly zero-energy building is a building with high energy performance since it requires zero or close to zero amount of energy, utilizing renewable resources[192].

Outlier data (anomalies) that need to be removed from the sample because may cause bias and the failure of the Multiple Regression model.

RAI defines that the openable window surface must always be higher 1/8 of the floor surface of each room (RAI: $S_{window,openable} \geq 1/8\ S_{floor}$).

RAI enhanced aims at overcoming the RAI definition, by including in the calculation also the glazing geometry and visible transmittance, the floor surface, and the outdoor obstructions.

SDA: spatial Daylight Autonomy ($sDA_{300/50\%}$) (%) is the percentage of the area with a minimum of 300 lux for 50% of the operating hours per year. It is divided based on LEED into low daylight (0-55%), high daylight (55-75%), and very high daylight (75-100%)[193].

Sky View Factor SVF (%) is the ratio of the illuminance measured at the center of a façade (at the floor height) to the illuminance of a surface that can 'see' the whole sky dome. It is the measure of the amount of sky 'seen' by the windows of the façades with significant openings, calculating the square meters of each surface and finally weighting all the façades to get a single result for each unit considered.

UDI: Useful Daylight Illuminance (%) is the percentage over the regularly occupied hours (8 am - 6 pm) over one year when illuminance is useful, underlit and overlit. It is defined as 'exceeded threshold' when it is over 3000 lux (UDIe), 'achieved' when between 100 lux and 3000 lux (UDIa), and 'fell-short' when below 100 lux (UDIf).

View Out and *view quality* are included in both *LEED Protocol* and *EN17037:2018 - Daylight in Buildings*, stating that a maximum of three layers can be seen (ground layer, natural-urban landscape layers, and sky layer) from a room.

[192] *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Official Journal of the European Union, L 153/13, Strasbourg.

[193] I. Turan *et al.*, (2020), *The value of daylight in office spaces*, Building and Environment 168 (2020) 106503, pp. 1-13.

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I hope I made you proud.

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