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3. SUSTAINABLE NEW BUILDING TYPE: HOUSE AND OFFICE

3.1. Introduction

Nowadays buildings are responsible for 33% of the global energy demand (REN21 Secretariat, 2021) and 36% of greenhouse gas emissions (GHG) into the atmosphere (European Commission, 2020). Only the 15% of the energy needs required by buildings sector is powered by renewable energies (REN21 Secretariat, 2021).

The Italian situation reflects the International and European ones with about 40% of final energy demand required by residential use and only 19% of primary energy demand is satisfied by renewables (ENEA, 2021).

From 2015 Europe with the UN Agenda 2030 for sustainable development imposes to Member States the 17 goals for sustainable development (SDGs): "*to eradicate poverty, find sustainable and inclusive development solutions, ensure everyone's human rights, and generally make sure that no one is left behind by 2030*" (European Commission, 2015). Signing the European Green Deal the Member States highlights that the building sector is a key and fundamental point of this agreement to achieve energy saving and GHG reduction in the next future. Thinking about climate action, responsible consumption, sustainable cities and communities and affordable and clean energy goals.

In accordance with the main current European goals of minimizing CO_2 emissions to obtain a carbon-free economy within 2050 and of increasing energy efficiency up to 32.5% within 2030, a substantial change in building design is required.

It is now proved that all the design choices made at the initial stages of the design process considerably affected energy and environmental parameters (for instance primary energy demand, global warming potential etc.). Consequently, a sustainable multidisciplinary approach must be necessarily adopted in the design procedure to achieve nearly zero energy (nZEB) and environmentally friendly buildings: both energy and environmental performance must be considered starting from the earlier phases of the decision-making process. Building performance is surely influenced by several building typological factors (such as shape, sizing, orientation, internal distribution of functional units, window-to-wall ratio – WWR etc.) but also by technological system (for instance the choice of technological solution for the external envelope), involved in the beginning of the design process. Moreover, it is essential to carry on a study on building systems and their integration with renewable resources to produce green energy. So, it is worth noticing that the building distinguishing features become real passive strategies to be used to avoid energy-intensive buildings and to reduce GHG emissions in the context of the 2015 European Paris Agreement (European Commission, 2015).

In the following paragraph, after a brief introduction, some guidelines and design criteria will be outlined for both house (Valori, 2012) and office building [Miceli, 2016] types. It is helpful for the designers in the early stages of the design process to make the proper choice in relation to the main building typological factors, with the aim at achieving a sustainable and low-carbon building.

3.2. Residential Buildings

A quarter of Italian residential building stock was built before 1946 [ISTAT, 2018] and according to the last census performed by ENEA (Italian National Agency for new technologies, energy and sustainable economic development), 41% is classified as energy efficiency class G (ENEA, 2020) (global energy performance index for non-renewables $EP_{gl,nren} > 3.5\ EP_{gl,nren,rif,standard(2019/21)}$ reference building global energy performance index for non-renewable) (Italian Government, 2015). Some authors (Bianco et al., 2022) in literature highlights that with a substantial renovation (concerning both the external envelope insulation and heating systems) of the Italian residential building stock it is possible to achieve an energy saving of about 100 TWh by 2030 and 120 TWh by 2040. This scenario of a complete decarbonization of private house sector by 2050, as requested by Europe, will be only possible with the substitution of traditional fossil fuel with renewable energies to produce energy for both heating and cooling.

In recent years, especially between 2016 and 2019, an increase in sustainable residential constructions is indeed registered and 50% of the new buildings are classified as energy efficiency class A (ENEA, 2020) ($EP_{gl,nren} > 3.5\ EP_{gl,nren,rif,standard(2019/21)}$) (Italian Government, 2015). This is an obviously consequence of the Italian energy policy that, with the Ministerial Decree of 2015 called "Minimum Requirements Decree" (Italian Government, 2015), transposing the European directive 2010/31/UE (European Commission, 2010) and following, imposes that all private buildings must be nZEB from January 1st, 2020.

Since 1990, with the Agenda 21, when the concept of sustainable development became a key point also for architecture and building design, many experiences related to environmentally friendly residential construction have followed till the present date. In this regard, it is worth mentioning the experience of Prisma residential complex sited in Nuremberg (Germany), designed by Joachim Eble and built in 1997. This is an example of bio architecture: the building internal courtyard is characterized by East-West orientation to exploit solar radiation through the several transparent façades, the glazed roof is designed to be opened during summer season to guarantee passive cooling in nighttime and the rainfall water is storage to be reused in six different water towers, as a strategy for summer conditioning (Sympa, 2011).

The same architect participated in the design of the ecological district "Eva Lanxmeer", located in Oland, and built between 1998 and 2000. The greenhouse houses represented the key constructions in this neighborhood; they are characterized by a glazing external envelope that encloses the entire building maintaining proper internal thermal conditions for the occupants (Zonato, 2019) especially during winter season exploiting solar gains. There are many representative examples of sustainable and ecological districts and within 2030 they will be more. For instance, the Solar City district located in Linz is designed to maximize the energy saving exploiting the solar radiation or the BedZED in London should be considered the first nZEB and low-carbon district built between 2000 and 2002. In this residential and office district several active and passive strategies are used to minimize CO_2 emissions in the atmosphere such as solar and photovoltaic panels for domestic hot water and electrical energy respectively, windcatchers for passive cooling, all buildings are properly oriented in the construction site depending on the intended use and all materials have low environmental impact. Finally for the sake of completeness the Hammarby Sjöstad in Stockholm and the Masdar city, located in Emirates should be mentioned. They are both pioneer of smart and sustainable cities with the aim at nullifying the CO_2 emissions tackling climate change.

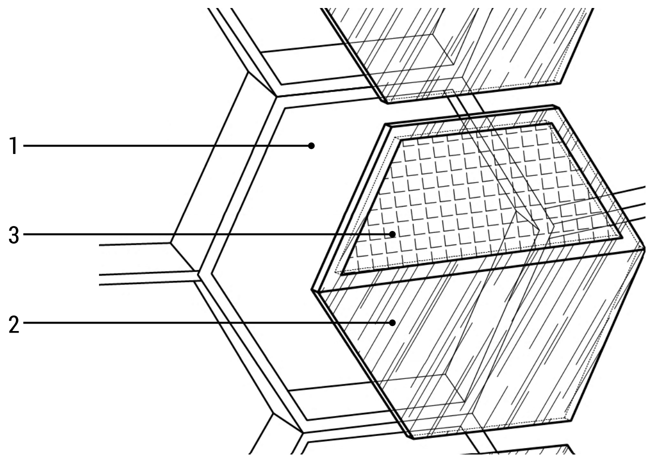


FIG. 3.1. Sketch of the Trombe walls in the southern facades of the building (Source: Valori, 2012) In the figure: 1 is the Trombe wall, 2 stands for openable double-glazing and 3 is transparent photovoltaic cell

As far as residential complex is concerned, it is worth to highlight the project called "*Uovo di struzzo con occhi di mosca*" (Ostrich egg with fly eyes) by Giuseppe Magretti (Archingegno Office) in 2010 for the city of Milan (Archingegno, 2010). The compact shape with a cyclical plan and the elliptical section (S/V – Surface/Volume ratio equal to 0.25 m^{-1}) lets to achieve the best internal comfort and well-being for the occupants for both winter and summer season. The main passive strategies are the southern external walls made of Trombe walls and small greenhouses for a total surface of 180 m^2 and a solar gain of about 5.5 kWh/m^2 (if located in Milan). Furthermore, there is a thermal water wall in the center of the building throughout its height. This passive solar system lets to storage the heat due to solar radiation and then to release it in the internal environment helping to warm up functional units. The total energy produced is equal to 5.5 kWh/m^2 (if located in Milan) (Fig. 3.1).

Another interesting research project about residential complex is done by Mario Cucinella Architects. It is called "House 100k" (Mario Cucinella Architects, 2007). The research aims at outlining a sustainable, carbon neutral and affordable residential building type of about 100 m^2. The idea is combining active and passive strategies to make the building energy independent. Energy demand should be satisfied through renewable energies: solar, geothermal and wind energy should be used to meet the electrical energy needs.

Obviously, there are also many representative examples of green and sustainable architecture built in Italy and abroad. The following ones should be mentioned because they are near past constructions looking to the future and making nature the key point of the architecture: the "One Central Park" by Jean Nouvel (Sydney 2014) and the "Torino Green", by Luciano Pia (Turin, 2012). The last one is a curious residential complex where the vertical green becomes a real part of the façades through tanks and tall trees (Galateo, 2016). They contribute to the regulation of the external climate conditions, minimizing both the façades surface temperature during summer season as sola shading system and the heat islands effect throughout the whole year. Moreover, during winter season, they protect buildings from cold wind.

3.2.1. External Layout

Firstly, it is advisable to highlight that the design of the external layout obviously depends on the geometry of the available construction site and the number of residential buildings to be constructed. Thus, since the proper external quality must be guaranteed in the project of the external environment to ensure the wellbeing of the occupants and to reduce the heat island effect. For instance, in the project of "MilanoSei" by Mario Cucinella Architects in 2018, the main purpose is a green and sustainable city district where the new design complies with the existing natural environment and infrastructure. Several green areas and trees are considered in the project of the external layout. Moreover, all the design buildings must have the opportunity to exploit the available natural resources as passive strategies such as, for instance, solar radiation or vegetation. The Gneiss Moss residential complex of about 61 houses designed by Georg W. Reinberg and built in 2000 (Salzburg) is a key example of the previously highlighted strategy. The distance between the different buildings (6 residential buildings) is calculated to all the southern façades (characterized by the presence of solar greenhouses) received the higher solar radiation to exploit for heating during winter season.

The advisable configuration for the external layout is one that guarantees the following advice for winter and summer seasons, respectively:

Winter Season
- To regulate the proper distance between buildings to exploit solar radiation and to save energy for heating.
- To avoid natural vegetation shadows or those of neighbor buildings.
- To northern orientate evergreen tall trees to avoid cold winds and to southern/eastern/western orientate deciduous trees to exploit solar gains.
- To orientate the buildings in the construction site to use all natural sources for conditioning (for instance exploiting solar radiation trough glazing façades as passive strategy to heat internal environment) or electrical energy production.

Summer Season
- To design external vegetation as to solar shading system: to avoid overheating inside the buildings.
- To orientate the buildings in the construction site to use all natural sources for conditioning (for instance exploiting prevailing winds through windows as passive cooling to cool internal functional units).
- Especially for climate zone with very warm summer: to use external finishing materials characterized by higher reflection coefficient.

Generally, some advisable design principles for a residential complex external layout are the following ones:
- The construction site should be characterized by at least 25%. permeable flooring or green areas Also, the parking area should be included in the previous permeable areas.
- The construction site should be in an area served by basic services and infrastructure as required by many environmental protocols (such as ITACA protocol or LEED one).

3.2.2. Energy Strategies

In the following 2 subsections, both winter and summer season energy strategies and environmental ones are shown in detail for residential building type. Some examples are alscited. In general terms, for all temperate climate it is possible to individuate some strategies that aim at decreasing primary energy demand for summer and winter season, primarily exploiting the distinguishing climate characteristics of the construction site. For instance, related to some seasons features it is worth to notice as follows:

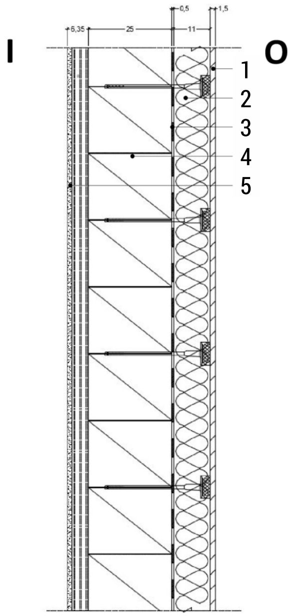
- *Temperate climate with cold winter*: the first goal is to reduce energy needs for heating because in this type of climate this contribution to the energy balance of the building is higher than the others.
- *Temperate climate with warm summer*: the first aim is decreasing the primary energy demand for cooling, paying particular attention to the overheating of the functional units during summer season.
- *Temperate climate with summer droughts*: in this case the decrease in energy demand during summer season is the main goal because this contribution is the highest one in the building energy balance. In fact, the energy need for winter season is limited.

Both winter and summer strategies must be chosen considering the highest contribution to the building energy balance, according to the climate characteristics.

3.2.2.1. Winter Season

In areas where the energy needs for heating is prevalent, to decrease energy demand, the energy strategies should be the following ones:

- Low value of the surface-volume ratio [m^{-1}] (surface means dispersing surface and volume means conditioned volume). Usually, this value is lower than 0.55 m^{-1} for a building characterized by a geometry that positively contributes to the energy performance. In this case the building will be surely characterized by a compact shape.
- Main orientation of the façades along East-West axis to exploit solar gains in cold winter days. As shown in detail in the next paragraphs, the main functional bands should be southern oriented and should hosted the primary functional units. Otherwise, the secondary ones should be northern oriented and hosted the ancillary premises that become buffer space to avoid significant heat losses.
- Regarding window-to-wall ratio (WWR): reducing the northern glazing parts to minimum required by health-hygiene standards for the specific intended use of functional units and increasing the southern WWR up to 40%-50% to catch maximum solar radiation during the day (to maximize solar gains).
- To protect the building from cold winter winds through natural (if available on site is preferred) or artificial barriers to limit dispersions by convection.
- Regarding technological solutions to adopt for the external wall the ETICS (External thermal Insulation Composite System) (Fig. 3.2) should be one of the alternatives used to minimize heat losses, to eliminate thermal bridges (also at the structure) and to reduce initial investment costs as well.



Legend
(outside-inside)
1. External finishing plaster with glass fibre net (15 mm thick)
2. EPS thermal insulation panel (110 mm thick)
3. Adhesive (5 mm thick)
4. Lightweight bricks (250 mm thick)
5. False wall made of: metal substructure and plasterboard panel (12.5 mm thick)

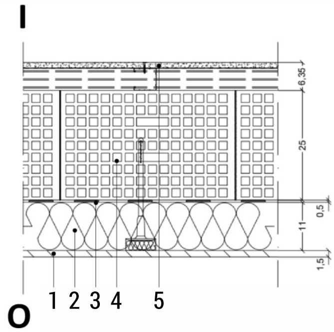
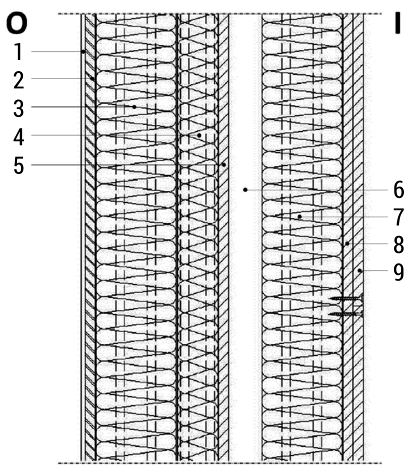


FIG. 3.2. Sketch of ETICS solution stratigraphy to be used in a sustainable residential building. The thickness of insulation is outlined considering Florence climate characterized by 1821 HDD (Source: own elaboration)

The other technological solution that could be used for a sustainable residential building is a dry one (Fig. 3.3). In this case, the advantage is surely economical, mainly linked to the time of the construction, which is shorter, if compared to the traditional technological solutions.



Legend
(outside-inside)
1. External finishing with glass fibre net (5 mm thick)
2. Cement board with glass fibre net on surfaces (12.5 mm thick)
3. Rock wool thermo-acoustic insulation panel with density equal to 70 kg/m^3 (100 mm thick)
4. Wood fibre thermo-acoustic insulation panel with density equal to 270 kg/m^3 (50 mm thick)
5. Air (41 mm thick)
6. Rock wool thermo-acoustic insulation panel with density equal to 70 kg/m^3 (100 mm thick)
7. Plasterboard panel (12.5 mm thick)
8. Plasterboard panel (12.5 mm thick) with vapour barrier made of aluminium sheet (0.025 mm thick)

FIG. 3.3. Sketch of dry solution stratigraphy to be used in a sustainable residential building. The thickness of insula-tion is outlined considering Prato climate characterized by 1668 HDD (Source: own elaboration based on Capitaneo, 2014)

However, there are several different technological solutions for the external walls that can be used and which are characterized by a continuous external insulation, ensuring decrease in heat losses. For instance, the rainscreen façade, but they are more expensive with respect the ETICS solution. As a result, these solutions are sometimes not economically convenient.

- To design in the residential complex passive strategies, properly oriented to catch the solar radiation during winter days and increase solar gains saving energy for heating. One of the possible passive strategies is the introduction of a southern solar greenhouse, as in the Gneiss Moss residential complex by Georg W. Reinberg (Saltsburg, Austria) or in the one designed by LOG ID (by Dieter Schempp) built in 1993 in Switzerland. Another different type of strategy is the Trombe Wall. This passive strategy is not recurrent in residential building; by the way there are some significant and representative examples to be highlighted such as the Solar House of Odelio, built at the end of XX century after several tentative to construct in the right way the Trombe Wall. Another example of a Trombe Wall is included in a research project of solar Decathlon 2014 by the University of Alcalà. They defined a prefabricated panel that includes a mix of clay and a PCM (phase change material). Finally, the last example is the residential complex in Marostica (Italy) designed by Cooprogetto in 1984, where there are both Trombe wall (Barra-Costantini system) and solar greenhouses.

In the following Figure 3.4 the passive strategy of the Trombe Wall used in Italy in a residential complex located in Rome, designed by Cortesini – Battisti – Tucci studio and built in 2007-2010. In this case the storage mass of the Trombe Wall is a solid mass and they are characterized by ventilation grid to exploit convective heat exchange. It is combined with a solar greenhouse to increase performance.

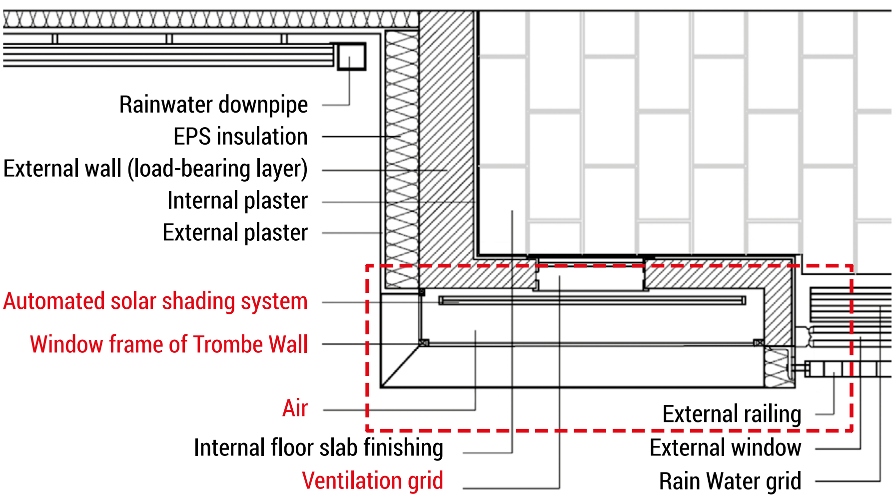


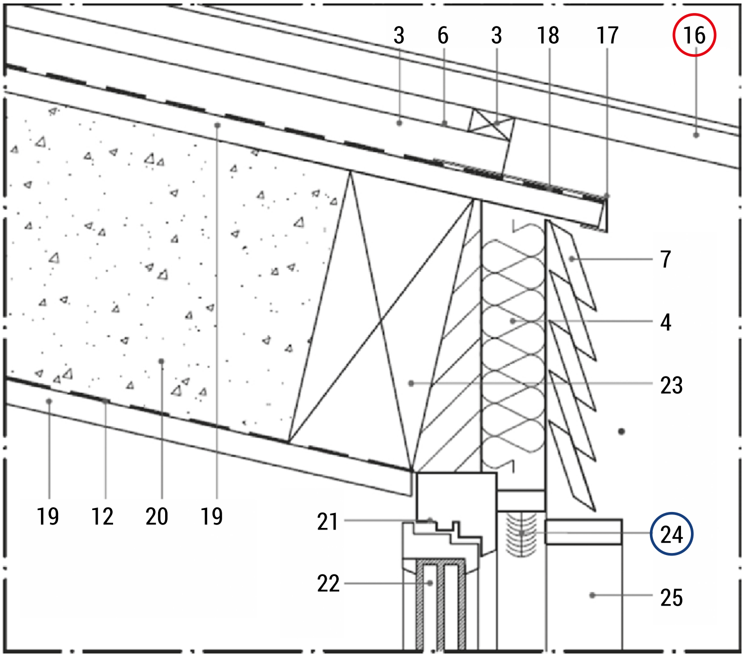
FIG. 3.4. Example of a detail of a Trombe Wall used in a residential complex located in Italy (Source: own elaboration based on Valori, 2012)

- If a ventilation system is included to guarantee the proper air change rate for this specific intended use, usually the exhaust indoor air is used to pre-heat the outside air exchange. This happens with solar greenhouse air as well. This system configuration is used in the Gneiss Moss residential complex by Georg W. Reinberg (Saltsburg, Austria) where the warm air inside the solar greenhouse is in fact used for this aim. Moreover, the exhaust air of toilets and kitchen is fed into a heat exchanger to pre-heat outdoor air for garage floor to minimize dispersions to these unheated secondary functional units.

3.2.2.2. Summer Season

In areas where the energy needs for cooling is prevalent, to decrease energy demand, the energy strategies should be the following ones:

- During summer season, to avoid summer overheating the main façades (especially southern and eastern oriented ones) should not be exposed to direct solar radiation during the warmest hours of summer days.
- Regarding the value of the WWR, it should be equal to the minimum required by health-hygiene standard to guarantee natural ventilation and lighting. This is necessary to avoid summer overheating in all the western, eastern and southern functional units. The better configuration is the one without eastern and western windows for primary functional units.
- To use solar shading systems to regulate the entry of solar radiation and so the value of the solar gains in the energy balance of the residential building. They are useful also to avoid glare in the primary functional units. In Italy they are required by legislation for South orientation. They can be fixed and so built through the geometry of the roof or directly at the windows with overhang. Otherwise, solar shading systems can be movable, with manual or automated control. These 2 different types of solar shading systems are utilized in a terraced residential complex situated Bolzano, designed by Michael Tribus and built in 2000-2001 (Fig. 3.5).
- To design natural and artificial barriers to enable fresh air enter the building to cool it during summer night and to increase the dispersion of heat storage during the day. At the same time to guarantee the proper shading of the internal functional units.
- To use in the residential complex some passive strategies to ensure proper internal air temperature during summer day and night to avoid an excessive use of cooling system and so to save both energy and money. A passive cooling during summer night is recommended. It happens when the outdoor temperature is less than the indoor one and the windows developed on opposite fronts of the building help it as well as non-excessive building width. It is possible to include some specific technological systems to ensure night cooling but at the same time people safety avoiding intrusions.

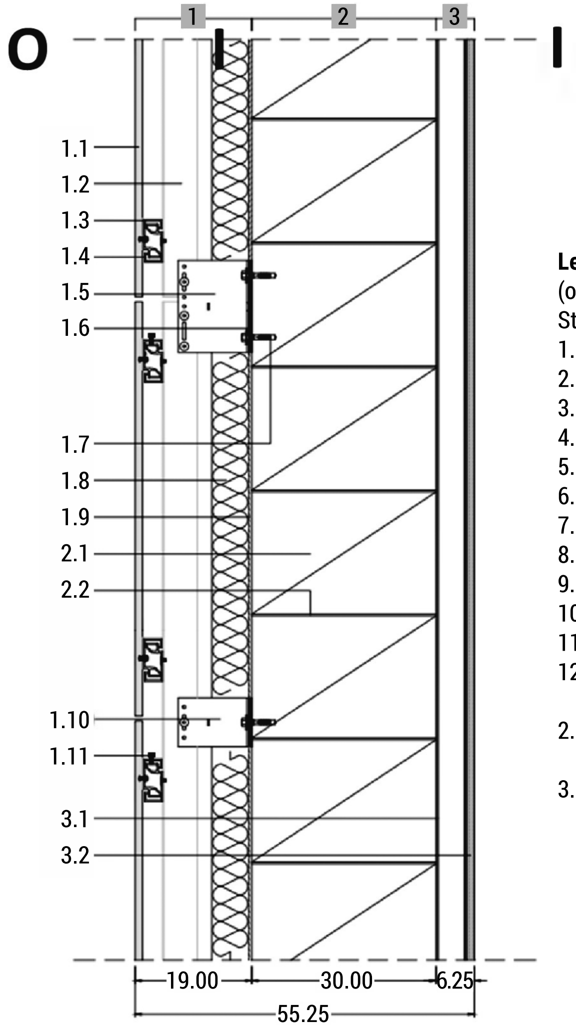


Legend

3. Wooden frame
4. Rock wool thermal insulation layer (80 mm thick)
6. Air (30 mm thick)
7. Wooden external finishing
12. Vapour barrier (0.5 mm thick)
16. Roof finishing (Fixed solar shading system)
17. Metal casing
18. Waterproof sheet (5 mm thick)
19. Wooden panel
20. Reinforced concrete slab
21. Wooden window frame
22. Double glazing
23. Wooding finishing element for roof stratigraphy
24. External blind (Movable solar shading system)
25. Wooding finishing element for external wall

FIG. 3.5. Sketch of a detail of a terraced residential complex in Bolzano with the indication of 2 different type of solar shading system: fixed one built with the finishing element of the roof top (red in figure) and movable one directly at windows (blue in figure) (Source: own elaboration based on Valori, 2012)

- Regarding the technological solution for the external wall, a stratigraphy characterized by a high surface mass [kg/m^2] is recommended to guarantee the proper time shift that for warmest summer is recommended greater than 8 hours to avoid inside overheating. A dry solution should be used but with a material for thermal insulation characterized by high density (> 70 kg/m^3). Moreover, the thickness of insulation should not be high (the minim required by legislation for minimum thermal transmittance and surely less than 16 cm) because this results in an increase in energy needs for cooling. One possible technological solution for the external wall is a rainscreen façade that allows to reduce the summer thermal load thanks to the ventilated layer (Fig. 3.6).



Legend
(outside-inside)
Stratigraphy Number 1

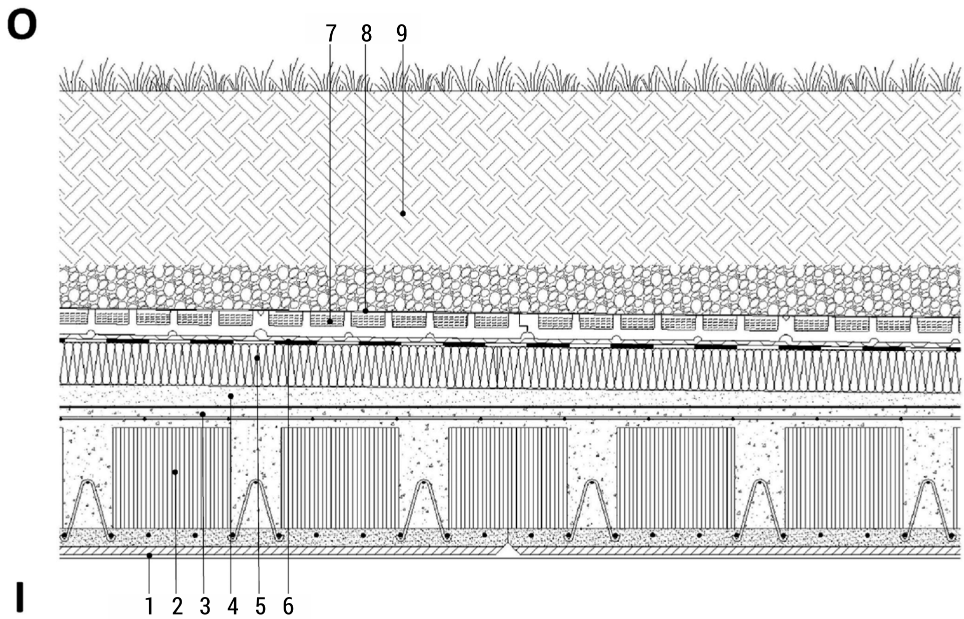
1. External finishing layer (Grès)
2. Vertical frame with T section (Aluminium)
3. Restraint clip
4. Horizontal frame
5. Fixing bracket (L section)
6. EPDM
7. Dowel
8. Thermal insulation material in rock wool
9. Adhesive
10. Fixing bracket (L section)
11. Setting crew
12. Sealing element for installation

2.1 and 2.2 Aerated concrete blocks

3.1 and 3.2 False wall with plasterboard panels and metal substructure

FIG. 3.6. Sketch of the stratigraphy of a rainscreen façade. The thickness of insulation changes with respect to the required minimum thermal transmittance with respect to the climate zone (Source: own elaboration)

- Otherwise, regarding the technological solution for the roof, the usage of green roof (Fig. 3.7) is recommended because it results in many advantages. For instance, it allows to reduce the roofing surface temperature compared to traditional finishings and consequently to improve the indoor thermal conditions and the occupants' well-being. Furthermore, it improves the microclimate conditions around the building, decreasing the heat-island effect, as well as obviously reducing CO_2 emissions.



Legend
(inside-outside)

1. Pre-mixed plaster with plastic net
2. Prefabricated floor-slab (Predalles type 240 mm + 50 mm)
3. Structural slab in reinforced concrete (50 mm thick)
4. Slope screed in lightened reinforced concrete (minimum thickness equal to 50 mm)
5. EPS thermal insulation (100 mm thick)
6. Waterproof sheet (5 mm thick)
7. Storage and Drainage element (62 mm thick)
8. Geotextile sheet
9. Soil for vegetation (450 mm thick)

FIG. 3.7. Sketch of the stratigraphy of a green. The thickness of insulation changes with respect to the required minimum thermal transmittance with respect to the climate zone (Source: own elaboration based on Capitaneo, 2014)

3.2.3. Environmental Strategies

In the context of the Paris Agreement, the environmental strategies to minimize the environmental impact for a residential complex should be the following ones:

- To use natural materials or materials with a proper percentage of recycled content, according to CAM (Minimum Environmental Criteria) to build environmental-friendly residential complex. The Global Warming Potential[1] of a construction is mainly related to the Life Cycle Assessment of materials as well and not only to the operational phase. It is better to choose materials produced near the construction site to reduce CO_2 emissions for transportation as well.
- To use passive strategies for summer and winter seasons to decrease the energy needs powered by heating and cooling systems.

- To produce energy using renewable energies to reduce the environmental impact of the operational phase. The use of active strategies is by now essential and indispensable to produce energy to satisfy building needs as well as at the same time an amount of energy to store and to fed into the grid in the context of the construction of plus energy buildings and districts and consequently smart cities. In a residential complex named "Sunny Woods" designed by Beat Kämpfen located in Zurich (Switzerland) built in 2000-2001 the solar collectors to produce service hot water are integrated in the southern façade of the building through the railings of the terraces while the photovoltaic (PV) system on-grid to powered electrical energy is installed on the roof top.

  Regarding active strategies installation and plus energy houses, it is worth to notice a German project. It is a two-story home (260 m^2) located in Leonberg (Germany), and built in 2010. The system is characterized by 15 kW_p PV system installed on the roof top, integrated with an electrical heat pump, and 7 m^2 of solar collectors. A significant amount of surplus energy is produced since the first year of operational phase (Fisch et al., 2013).

3.2.4. Building Orientation

For building orientation, the solar radiation is one of the main parameters to consider because it obviously influences the energy saving in both summer and winter season. In fact, it affects the internal distribution of functional bands, the internal layout of primary/secondary functional units, the window-to-wall ratio on the façades and the design of necessary solar shading systems for different orientation.

For this reason, the preferable orientation for a residential building is along the East-West axis, due to the possibility of maximizing the solar gains during winter season and consequently save energy for heating. At the same this configuration lets to receive less incident solar radiation on building façades during summer season, due to the greater inclination of solar rays and consequently save energy for cooling and avoiding overheating in the internal environment. By the way it is possible to achieve the same energy and environmental performance during operational phase of the residential building if it rotates maximally 20° anti-clockwise and so obtaining the main façades eastern-southern oriented.

Otherwise, the orientation of the building is obviously affected by the geometry and natural constraints of the construction site. For this reason, some considerations must be done to highlight the main possible issues:

- If the possible orientation of the main axis of the construction is along North-South direction the main issue is related to both the significant decrease in solar gains during winter season and the western orientation of the main façades for summer season. Thus, because the incidence of solar radiation on main fronts happens during the warmest hours of summer days. Moreover, another significant issue consists in designing proper solar shading systems for eastern-western glazing parts to avoid overheating in internal functional units.

The first problem can be solved through the design of southern oriented glazing elements for instance through the construction of overhanging portions or the introduction of passive strategies such as solar greenhouses. The residential complex located in Vienna (Austria) designed by Georg W. Reinberg and built at the end of XX century is characterized by a main orientation along North-South axis. The designer to improve the energy performance of the building introduced for each single apartments a double-height solar greenhouse to exploit solar gains during winter season. The geometry of the building is designed with several variation of the height of the different houses to let the solar radiation enter in the internal spaces.

- If the possible orientation of the main axis of the construction is along Northeast/Southwest or Northwest/Southeast, the building should receive solar radiation through southwest and southeast windows during winter season. In this case the advisable orientation of main fronts to limit the possible overheating during summer season is along Northeast/Southwest axis because the solar radiation on the main fronts is at the beginning of the day.

3.2.5. Geometry of the Building

Firstly, the geometry of the building and, consequently, the shape of the floor plan, the section geometry and finally the roof one, depends not only on the available construction site but also on the characteristics of the climate and on passive strategies that the designer wants to use. Generally, for cold climates (such as Italian climate zone F, characterized by heating degree days HDD > 3000 Kd/y or E defined by 2100 < HDD < 3000 Kd/y (Italian Government, 1993)) a compact shape with a low value of the surface/volume ratio (S/V [m^{-1}]) is advisable to reduce the dispersions during winter season. Otherwise for warm-humid climate a linear shape is better to ensure cross ventilation during summer season to avoid overheating exploiting passive cooling.

In the next paragraphs, the geometry of the floor plan, section and roof of the sustainable residential building is analyzed in detail.

3.2.5.1. Floor Plan Geometry

The floor plan geometry undoubtedly influences the housing aggregation, the orientation of the functional bands and functional units, the internal layout of each single house but also natural lighting and ventilation inside the environment. It is worth to notice that there is not an optimum floor plan geometry in absolute terms but there are many possibilities to be used by designers. Then, the orientation of the primary and secondary functional units (as passive strategy) influences the energy performance and so make the building more sustainable.

The geometry of the floor plan for a sustainable residential complex could be:

- *Square*: it is usually used in climate typified by cold winter because it is characterized by high compactness (low S/V for instance < 0.50 m^{-1}) that guarantees to minimize dispersions. Usually, the stairs are placed in the center of the squared shape and to ensure proper lighting and thermal conditions, the floor plan could be rotated of about 45°. Like this there is not a completely northern oriented façade (adverse orientation) as demonstrate in Figure 3.8.

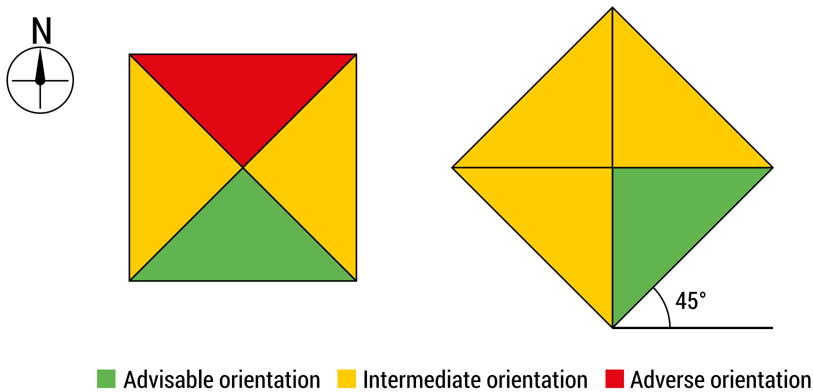


FIG. 3.8. Individuation of advisable, intermediate, and adverse orientation for a squared residential complex (Source: own elaboration based on Valori, 2012)

One Italian example of this type of configuration is a small housing complex built near Florence (climate zone D HDD = 2182 Kd/y). It is designed by Tiesse Ingegneria s.r.l., and built in 2005. It is a detached building developed onto 2 floors and accommodates 2 houses. It is oriented in the construction site rotated of 45° with respect North-South axis to guarantee a favorable orientation to the primary functional units of both houses.

- *Rectangular*: this configuration is the most recurrent one in residential building complexes. This shape is characterized by 2 symmetry axis and by one dimension greater than the other. It is generally used in several climate zones because, if properly oriented (the main fronts along East-West axis), the linear shape ensures significant solar gains during winter season and consequently energy for heating can be saved. This configuration allows to southern oriented most primary functional units and develops the secondary one northern oriented using them as buffer spaces to avoid dispersions during winter season (passive strategy).

If the East-West orientation is not possible for this kind of shape, for buildings located in the Mediterranean area, the advice is to rotate the building in such a way as to have the main façade South-East oriented. This enables to obtain solar radiation and natural lighting during the beginning of the day. Thus, minimizing the western exposure that in summer season can create overheating phenomena inside the functional units (Fig. 3.9).

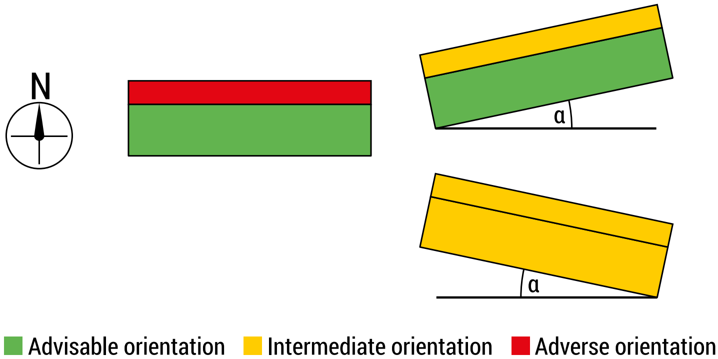


FIG. 3.9. Individuation of advisable, intermediate, and adverse orientation for a rectangular residential complex (Source: own elaboration based on Valori, 2012)

It is worth noticing that residential complexes could be designed also with *C shape, L shape* and as *courtyard building*. This type of shapes is less common in sustainable residential buildings because the C and L shapes are characterized by low compactness. If the building is East-West oriented there always will be some primary functional units not properly oriented. Courtyard buildings as well presents some critical issues especially related to the shadows of some parts of the building on others. This type of building, characterized by more articulated shape, surely have higher primary energy demand with respect to compact shape considering the same boundary conditions (such as climate zone, thermo-dynamic properties of the external envelope, air change rates for this intended use etc.).

3.2.5.2. Section Geometry

The geometry of the section of a building depends on several factors: firstly, obviously, on the internal layout and so on the distribution of functional bands and functional units, then on passive strategies used (such as fixed solar shading systems, solar greenhouses, ventilation chimneys or buffer spaces), but also on active strategies utilized that needed a specific orientation to be efficient. So, the geometry of the section as well contributes to make the residential building sustainable and influences its energy and environmental performance. Also in this case, the climate characteristics are fundamental to make the right decision about the section configuration. Some advice can be outlined to use the building shape as a passive strategy.

Cold Climate

- The stairs can become a buffer space to decrease dispersions to external environment during winter season (Fig. 3.10), but also some secondary functional units can be designed as buffer spaces to avoid heat losses such as, for instance, the garage. It occurs in the Premiere House (Treviso, 2011) where the northern garage become a buffer space for the home.

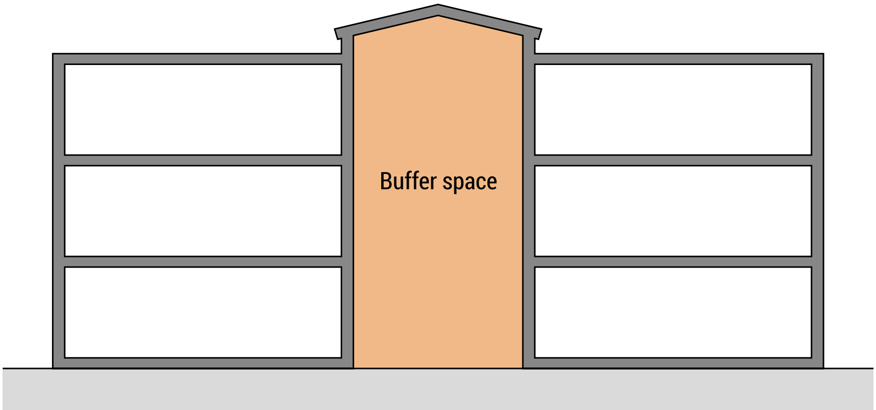


FIG. 3.10. Possible configuration of a residential complex to use the stairs as buffer space (on the left in the figure) (Source: own elaboration)

- The variation of the height of the façades with respect to the orientation is recommended. If the southern oriented front is higher than the northern one there surely are some energy advantages for cold climate during winter season: this configuration ensures an increase in solar gains for southern façade, as well as decreases heat losses for northern one. Thus, because the North front is developed onto less surface of the external envelope. The residential complex "SHE.AG1 Fastiggi House" is an example of this type of configuration with a trapezoidal cross section and, as a result, different heigh between northern and southern façade (Lusardi, 2008).

Warm Climate

- The introduction of ventilation chimneys to guarantee passive cooling during summer season is advisable. For instance, the residential complex "Giuncoli" located in Florence, is characterized by a rectangular section with 2 ventilation chimneys for each single building. This energy strategy exploits local prevailing winds to ensure passive cooling during summer night. The same strategy is used in the residential complex "Colle degli Ulivi", built in Frascati in 2016, that contributes to maintain the proper air change rate as well.
- The introduction of fixed solar shading systems, such as overhang along the façades (especially for southern oriented ones) or directly at the height of the roof plan, is advisable to regulate solar gains during summer season to save energy for cooling and prevent overheating during warm summer sunny days.

Finally, for different type of climates, the inclination of the front (usually South façade) of a building should be a strategy to improve the energy performance and, consequently, to reduce the environmental impact. For instance, in this case, the designer can have 2 possibilities depending on his goals:

- The first one is to slope the front upwards. This configuration is advisable when the main aim is exploiting solar radiation to produce energy with active strategies.

In this way, the façade receives the solar radiation even if the inclination of the solar rays is higher. At the same time, it is necessary to design right solar shading system to prevent summer overheating inside the functional units. Thus, can be reached creating the glazing parts of the façade set back from the main front. An example of this configuration of external wall characterized some residential complex in the Eva-Lanxmeer District (Netherlands, 2009).

- The second one is to slope the front downwards. This configuration is recommended when the front is characterized by the presence of a passive strategy (such as solar greenhouse). Thus, because the solar radiation can enter to the internal environment when the sun is low in the sky during winter season. Otherwise, the inclination avoids excessive solar gains during summer season. Some residential complexes in Gneiss-Moss (Saltsburg, 2000) district are an example of this previous possibility.

3.2.6. Building Functional Organization

Once defined the orientation of the building, the geometry of the construction (depending on the shape of the construction site), the energy strategies that can change the geometry of the section of the building (depending on the site analysis), it is possible to outline the internal layout and so the distribution of functional bands and functional units. In the next paragraph the internal layout of the main types of residential building are outlined, by proposing different configurations of the building type to improve energy performance according to climate characteristics.

Single-Family Building

If the residential complex is an aggregation of a single-family house (terraced house building type) and it is characterized by the right orientation (along East – West axis), the internal configuration should develop as in Figure 3.11. The functional distribution of each single-family house should be organized into 2 different functional bands with the southern one deeper than the northern one. The primary functional units (characterized by greater presence of people during the day such as living room, dining room or bedroom) (marked in green in Figure 3.11) developed in the southern oriented functional bands, while the secondary functional units (such as vertical/horizontal connections, toilets, storage) (marked in red in Figure 3.11) in the northern one. This internal distribution guarantees a better energy performance of the whole complex.

If the residential complex is situated in a cold climate, a solar greenhouse should be included along southern façade to increase solar gains during winter season. It should be characterized by a depth which is 2.50 m at least.

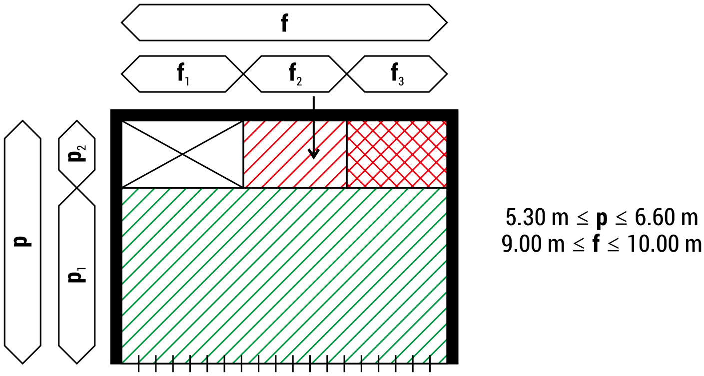


FIG. 3.11. Functional distribution of a terraced single-family house with the indication of the main dimensions of functional bands (Source: own elaboration based on Valori, 2012)

Otherwise, if the residential building is sited in a location characterized by a warm temperate climate the shape of the building should be less compact and so developed with higher width size. In this configuration, the needed solar gains for winter season are nevertheless ensured as well as natural ventilation for passive cooling is promoted. In this case an internal courtyard or a southern loggia are usually developed, to manage passive cooling (Fig. 3.12).

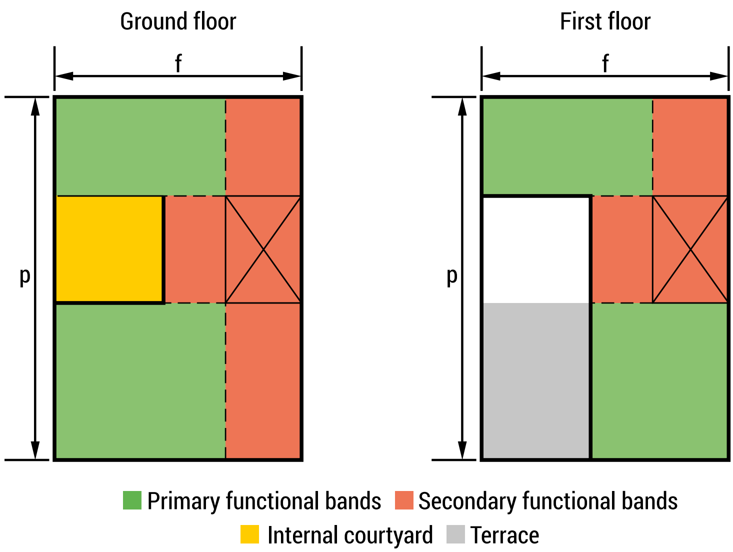


FIG. 3.12. Distribution of single-family house (possible aggregation for terraced buildings) for warm temperate climate with the integration of solar greenhouse and internal courtyard to increase energy performance of the building (Source: own elaboration based on Valori, 2012)

An example of this building type with the introduction of an internal courtyard is the residential complex designed by Solinas Verd Architectos and built in Seville (Spain, 2006-2008). Every single house is characterized by a linear shape; in this case, a solar greenhouse and an internal courtyard are included in the design to ensure proper solar gains and to avoid overheating, exploiting natural ventilation really thanks to the patio.

If the single-family residential complex is mainly northern-southern oriented, it is possible to construct some glazing elements (for instance solar greenhouse), jutting out of the building (upwards), to guarantee needed solar gains during winter season and to save energy. The already mentioned residential complex by Georg W. Reinberg in Sagedergasse is a representative example.

Multi-Family Buildings

As far as multi-family buildings (in-line and gallery building type) concerns the best geometry for the construction in this case is also the linear one, with the same internal layout developed into 2 different functional bands. The depth of the building varies in a range between 8-10 m. The difference with the single-family house is obviously the presence of the vertical connection.

As in the case of terraced buildings, a solar greenhouse can be included in the building with proper orientation (South), and it can be designed along the main southern façade (Fig. 3.13 – left side). As an alternative, if for instance the geometry of the construction site does not allow the previous configuration, the public horizontal connections (near the stairs block) can become the solar greenhouse as illustrated in Figure 3.13 (right side).

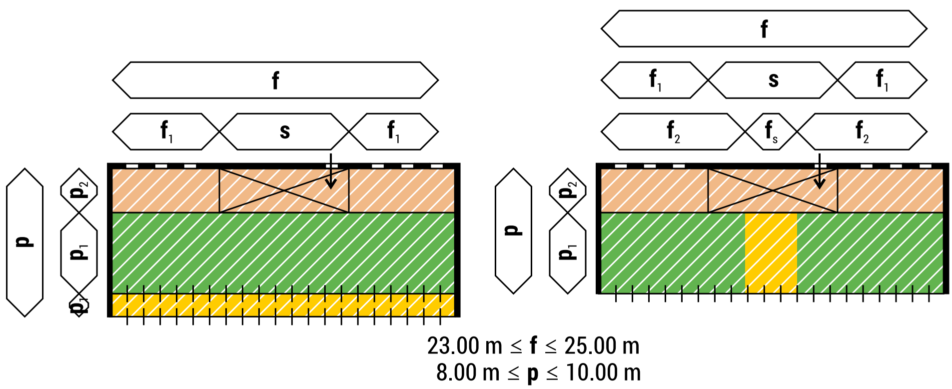


FIG. 3.13. Functional distribution of an in-line multi-family house with the indication of the main dimensions of functional bands and possible integration of a passive strategy (solar greenhouse) in 2 different ways. In the Fig. in red there is the secondary functional bands, in green the primary functional bands and in yellow the possible integration of the solar greenhouse (Source: own elaboration based on Valori, 2012)

In both cases, the stairs are developed in the northern functional bands to become a buffer space to limit dispersions for the most disadvantageous orientation. For instance, the stored heat through this passive strategy during the day could be used to preheat the external air before enters to the internal functional units.

If the multi-family residential complex is mainly northern-southern oriented, as it happens with single-family buildings, it is possible to catch maximum solar radiation constructing the building in steps (change in the section geometry of the building) or building southern projection along east and West axis (Fig. 3.14 – right side). Another possibility to improve the energy performance of a building not properly oriented is to rotate the main axis of about 30° and to include solar greenhouses along South-West façade. In this case the projections of the external wall can be used as solar shading system (Fig. 3.14 – left side). In this configuration, the East and especially West fronts are designed to catch the solar radiation during winter season and to regulate it during summer one.

Regarding the internal functional distribution, the layout configuration that ensures the best compromise between energy and environmental performance is the one that guarantees the double facing on opposite front. It happens for in-line, terraced or gallery building type. As shown in Table 3.1 the secondary functional units (such as toilets, sore room but also kitchen that is characterized by high value of internal gains) are developed northern oriented to function as buffer spaces between internal and external environment. The main functional units should be southern oriented to ensure right solar gains and proper natural lighting during the day.

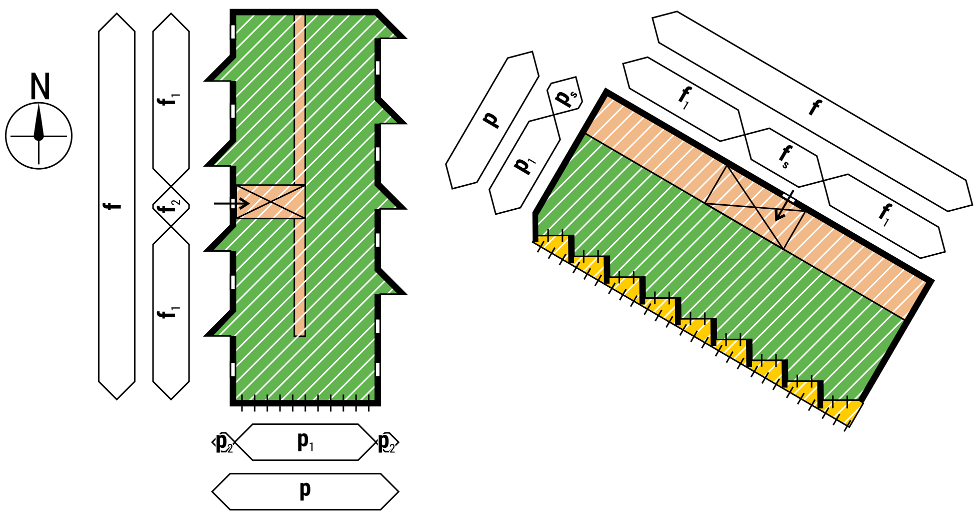


FIG. 3.14. Possible functional distribution to catch solar radiation (in 2 different ways) of an in-line multi-family house with the main axis northern-southern. In the Fig. in red there is the secondary functional bands, in green the primary functional bands and in yellow the possible integration of the solar greenhouse (Source: own elaboration based on Valori, 2012)

TABLE 3.1. Optimum functional units' orientation for residential buildings (Source: Valori, 2012)

Functional units orientation								
Functional unit	**N**	**NO**	**O**	**SO**	**S**	**SE**	**E**	**NE**
Living room			O	V	X	V		
Living/dining room			O	V	X	V		
Kitchen	X	O			O	O	O	V
Kitchenette	X	O				O	O	V
Double bedroom					X	V	V	O
Single bedroom			O	V	X	V		
Guest room					X	V	V	O
Study			O	V	X	V	O	
Bathroom	X	V	O				V	V
Utility room	X	V	O					V
Laundry	X	V						V
Garage	X	V	O					V
Horizontal connection	X	V						V
Store room	X	V						V
Stairwell	X	V	O					V
Technical rooms	X	V	O					V
Terrace			V	X	X	X	V	
Porch			V	X	X	X	V	
Greenhouse					X	V		
X optimum orientation	**V discrete orientation**		**O good orientation**				**bad orientation**	

3.2.7. Window-to-Wall Ratio

As far as window-to-wall ratio concerns, it is first worth noticing that the glazing part of the external envelope ensures both natural lighting and ventilation but also regulate the heat losses during winter season and yearly solar gains. So, they significantly influence the energy performance of the building whatever is geometry in plan or section. In the design and sizing of the glazing elements, it is fundamental to consider the orientation, but also the minimum air change rate and natural lighting required by legislation for this intended use. The advisable configurations, considering the climate characteristics, are the following ones:

- Cold climate: large size windows for South orientation. Thus, because the southern oriented windows catch direct solar radiation for the whole year and so this configuration ensures the maximum value of the solar gains to save energy during winter season. The WWR should varied between the minim value required by health-hygiene standards and 50%. A higher value of the WWR results in an increase in heat losses, due to the different of thermal transmittance between opaque and glazing external envelope. As regard summer season, the solar radiation is minimal due to the higher inclination of solar rays. For North orientation the glazing elements should be kept to a minimum and if they are present, they should be sized according to the health-hygiene standards.

- Warm climate: the dimension of windows should be limited to avoid excessive overheating of internal functional units and consequently an oversize for cooling system. So, in this case for both North and South orientation, they should be sized to guarantee minimum natural air change rate and lighting.

For both different types of climates (cold and warm), regarding southern orientation a solar shading system is needed to avoid the glare phenomenon, especially when solar rays have low inclination (winter season). Otherwise, for North orientation this issue influences on a lesser extent because the glazing elements receive only diffuse solar radiation.

The East and West glazing elements should be avoided. Thus, because they receive the maximum solar radiation in summer season during the warm daily hours and so this surely results in an overheating for the internal functional units.

Once defined the dimension of the glazing elements in the façade, considering climate characteristics and orientation, it is fundamental to consider also the geometry, the position with respect to the external envelope and the technological solutions for the glazing elements in order to regulate, not only energy performance but natural lighting as well.

- The best geometry to ensure the proper value of daylight factor is the squared one even if the rectangular one can guarantee direct lighting for a greater number of hours.
- The slope of the glazing elements should be considered. Thus, because the maximum solar radiation is achieved when the glazing surface is perpendicular with respect to the inclination of solar rays. Consequently, windows tilted upwards receive maximum solar radiation during the whole year.
- The position with respect to the external wall should improve the natural lighting inside the functional units. If the position is high on the façade a better natural lighting and the solar radiation entrance should be guaranteed for the whole width of the functional units.

Regarding the position of glazing elements in the façade it is worth to notice that for climate zones characterized by warm summer season it is necessary to guarantee passive cooling during night hours. The better configuration to achieve cross natural ventilation is when the windows are placed in opposite fronts of the same building unit.

Finally, the advice for the technological solutions for the glazing element considering the orientation are the following ones:

- South, East, and West orientation: selective glazing or solar control glazing to avoid overheating.
- North orientation: low e glazing to avoid excessive heat losses during winter season.

3.3. Office Buildings

At the beginning of XXI century the Italian offices were energy-hungry buildings with a primary energy demand of around 250 kWh/(m^2y); of which one-third is due to artificial lighting (Fabrizio et al., 2011). Nowadays, according to the ENEA report concerning energy consumption in office buildings in Italy, most of the energy demand is for conditioning (57% both heating and cooling), then 25% of energy consumption is related to equipment and 17% for artificial lighting. The current Italian energy performance index for office conditioning (according to 2019 data) is equal to 13 x 10^{-3} Tep/m^2year (ENEA, 2019).

Offices are usually the main headquarter of a company and its appearance should remind visitors of what the company represents and this impact the geometry, colors and technological solutions used for the envelope.

These are some famous representative examples:

- BMW headquarters (designed by Karl Schwanzer, renovation, Monaco di Baviera, Germany, 2006). The museum is characterized by the geometry of a petrol nozzle and the high-rise skyscraper remember 4-cylindrer engine;
- The Longaberger's Giant Basket Building (since 2019 it is a luxury hotel, Newark, Ohio 1997). Its shape is similar to a basket directly taking up the geometry of the main product of the company;
- CMA CGM Tower (designed by Zaha Hadid Architects, Marsiglia, France, 2011). It keeps in mind a ship's prow since the company is one of the major manufacturers of transport by sea (Respi, 2015).

In the last few years, a significant attention to the well-being of the workers within the office space has been paid. This had contributed, for instance, in the development of the active design where the building itself promotes users' physical activities as important part of working life and time. The active design is nowadays developing also in the construction of both energy-saver and environmental-friendly offices.

The Bullitt Center is one of the most representative examples of this type of architecture, designed by the Miller Hull Partnership, built in Seattle in 2012. The internal atrium is characterized by the presence of a stair that develops for the height of the building distinguished by a glazing external envelope. Moreover, to improve green and health transport, for bikes and locker rooms for workers are offered.

At the same time, the building is a Net Zero Energy, with PV system that power 230000 kWh/year of electrical energy, 26 geothermal probes to complete the heat pump system for heating and cooling. Furthermore, it is Net Zero Water due to the complete use of rainwater for drinking and not-drinking water. Moreover, sensors for CO_2 levels, internal air temperature and artificial lighting control are included in workstation functional units to save energy (Saghetti, 2020).

Nowadays it is necessary to consider that the pandemic period of the last 2 years had inevitably affected the traditional way of working. It has made an impact on both the organization and the internal layout distribution of the workstations. For instance, during the design process of an office building today, it is necessary to consider both working-from-home (remote working) and the office-based working. This is translated into a reduced number of fixed workstations into the offices with a rotation of employees (ex. app on mobile phone that can support the workers to reserve the office-space desk) and the increase of spaces for co-working and meetings.

In the context of both Paris Agreement (European Commission, 2015) and European Directive 2018/2002/EU (European Commission, 2018), it is fundamental and necessary to design new, smart, environmentally friendly office buildings characterized by low CO_2 emissions for construction phase as well as operational one and nearly zero energy needs. This goal can be obtained by acting on environmental and technological system of this building type as well as on active and passive energy strategies to adopt to reduce energy (both cooling and heating). Not least it is essential to produce electrical energy by renewable resources, not only to satisfy the minimum requirement of energy standards but to cover the building energy needs and to produce a higher amount of energy.

After analyzing different types of European sustainable offices, it is possible to outline some design guidelines and principles referring to two macro-category of buildings high-rise buildings and low-rise one. The first are characterized "*by a predominant horizontal development rather than in elevation. Levels are less than 10.*" (Miceli, 2016); while the second: "*have a vertical development with a small footprint. Levels are more than 10.*" (Miceli, 2016).

The design criteria for energy efficient offices are defined through several different categories: external layout, both energy and environmental design strategies, building orientation, geometry, envelope design (window-to-wall ratio related to glazing type and solar shading system), structural and technological solutions, systems, and renewables (PV system) (Miceli, 2016).

3.3.1. External Layout

Usually new office buildings are located in:

- Renovated areas for this specific intended use, close to the city center (for instance: Milan, Porta Nuova district, Italy) or in new expansion areas near the city.
- Suburbs close to the industrial facilities or in administration district (for instance: "Ropemaker" building designed by MAKE architects, London, UK, 2009).

- Residential districts where there is the intent to improve and renew an existing specific small area (for example: new headquarters of Dolce and Gabbana, in place of a 1950s residence, Milan, Italy, 2012).

Obviously, such as for houses, the offices external environment should guarantee the well-being of workers as well as decrease the building environmental impact, for instance reducing heat island effect using extended green area or guaranteeing green transport to use. By the way, there are some general design recommendations that can be followed:

- Shadows between buildings and from the surrounding natural/artificial environment should be avoided to allow the exploitation of solar radiation especially during winter season and to better design proper solar shading systems.
- Car parks located on the basement of the building should be preferred in order to both maximize green external areas and minimize the presence of the asphalt that caused the heat island effect. For instance, the Isozaki Tower in City Life, Milan, Italy, 2015 is characterized by a widespread area to include a green park, practically in the city center.
- Finishes of the external area should be characterized by materials with high reflectance coefficients to improve reflectance and especially reduce the high temperature of external sunny surfaces.

  Sometimes in order to reduce the external air temperature especially near glazing façade, external water tanks should be used. The external micro-climate should be better:
- Usage of vegetation and plants as natural barrier to protect the buildings from noise, winds, or solar radiation. Vegetation choice should vary depending on the climate zones, the scope, and the orientation. For instance, evergreen plants should be used for northern orientation to protect the façade by cold winds. While fleeting ones should be used for southern orientation to let the solar radiation enters during winter season and to shade the building façade during summer. For high rise offices this strategy is hardly applicable and usually vegetation is used only to shadow parking area. Finally, it is important the use of local plant and vegetation to reduce the water needs.
- The building should be well-connected with the city by public transports and stops should be near the offices, easily accessible for workers. Pedestrian and bike routes must be ensured and dedicated car parks for electric cars should be provided to improve green transport.
- In low-rise buildings usually the shape occupies the biggest part of the construction site, hence it is frequent that some internal functional units (for example atrium) are dedicated for common areas and shared functions. Sometimes they are directly connected with natural environment, for instance, the Federal Environment Agency building (Dessau, Germany, 2005), that has a big atrium characterized by extensive green areas and glazed roof to improve internal microclimate and natural lighting exploitation.

- In high rise buildings the shape occupies lower surface of the area hence the external area available is more extensive. In such case, it is strategic the position of the green area with respect to the building one. In fact, it is preferable to locate the green zone in the leeward position to avoid air vortex and have a better microclimate and comfort. For instance, GSW Haus designed by Sauercbruch Hutton Architects and built in Berlin (Germany) in 1999 (Miceli, 2016).

3.3.2. Design Strategies for Energy Efficient Offices

There are many design criteria applicable to offices that can impact on the energy performance of the whole building. These design criteria can be applied to offices to achieve the proper indoor comfort conditions for the workers throughout the year as well as saving energy (for instance for heating, cooling, lighting, and mechanical ventilation) and reducing the use of the mechanical systems. All energy strategies can be grouped according to the aim they are used for (reduction of both heating and cooling energy demand) or in relation to the natural resources they are exploited (solar radiation, wind, water, and soil). The strategies that can be adopted are both passive and active ones. The former allows to improve the proper indoor comfort conditions without considering the use of mechanical systems (as passive buildings): geometry and orientation of the building, insulation and airtightness of building envelope, solar shading systems, the design of openings.

The latter involves efficient technological systems solutions that can be used to produce energy from renewables exploiting natural resources (sun, water, winds).

For instance, the solar passive strategies are defined as: "*all devices, arrangements and construction criteria aimed at heating, cooling and air-conditioning buildings by means of the free energy contribution of the sun and of the possible natural resources of the local microclimate, without the aid of mechanical systems powered by exogenous energy sources. This takes place through natural thermal flows*" (Margini et al., 2008). Such as solar greenhouse, solar chimney, or roof pond.

The solar active strategies: "*are considered to be true technological alternatives to traditional devices, in which the various constituent elements are clearly distinguishable and require some form of energy supply exogenous to the system*" (Margini et al., 2008).

Some design criteria, aimed at reducing the heating demand of the building during winter season, are presented below.

- Adopt big glazing facade or windows, especially for South orientation and cold climates to exploit the solar radiation and save energy for heating exploiting free solar gains. According to the climate characteristics this passive strategy required the best compromise between heat gains, losses and natural lighting. Additionally, at the same time, it is important to consider the possible overheating during summer season and the need of natural lighting during working hours.

  It is proved that according to the orientation of the façades, the parameters to consider for the design of the transparent envelope are window area, glazing type and solar shading systems chosen. This because all significantly affect the building energy performance.

There are many offices characterized by glazing façades. Some examples are: The Salewa Headquarters designed by Park Associati with Cino Zucchi Architects Bolzano (Italy) in 2011 or the so called “the Hub” for the Atkins office built in Bristol (UK).

- Use of a buffer space to create an intermediate zone between outside and inside, characterized by intermediate hygro-thermal conditions (for instance an atrium functional unit). It is worth to notice that the temperature difference between internal environmental and buffer space is less than the one with the external environment. This permits to reduce heat dispersions (if closed) during winter months and to ensure passive cooling (if transparent parts can be opened) during summer period.

  For instance, the Federal Environmental Agency built in Dessau (Germany) and in the 3M Headquarters built in Pilotello (Italy). In both these buildings the internal atrium (used as buffer space) hosted plants and green areas, contributing to improve the microclimate during summer season, as well as avoiding overheating (cooling and ventilating).

At this point, a brief digression about atrium is necessary. It is worth noticing that the design of an atrium (as passive strategy) required to consider many parameters to improve the overall energy performance of the office building (Bazzocchi, 2013).

Firstly, it depends on the type of office building (low rise type or high rise one).

For low-rise offices, the design of an atrium is a recurrent design strategy that significantly affects the overall energy performance. Generally, it impacts the entire height of the building, and it permits the maximization of windows on both external and internal facades. It can be covered by a glazing roof (or a roof partly glazing and partly with PV panel integrated) where portion of it can be opened. In such case the greenhouse effect and the chimney effect are exploited to save energy for heating and cooling respectively.

Otherwise for high-rise offices the atrium would be developed only for few levels (ex.2-4 storey) and in such case it affects the overall energy performance to a lesser extent.

For design the atrium in low-rise buildings, to obtain both energy and environmental performance, it is fundamental to consider:

- The position relating to the geometry of the floor plan (EASE, 2015):
  - Attached: glazed and developed along one of the external walls of the building.
  - Linear: characterized by elongated shape between 2 building blocks.
  - Integrated: glazed and with one external façade.
  - Core: glazed and located in the center of the building.
- The geometry and the dimensions since they affect natural lighting.
- The presence of the roof (open or close) because it influences the S/V ratio [m^{-1}]. The S/V ration means the ratio between the dispersing surfaces and conditioning volume.

- The geometry of the roof (ex. flat roof versus shed one) since impacts on good both natural ventilation and daylighting (advantages to achieve).
- The automation of the roof (for instance the presence of several sensors to automatically open the transparent part of the roof).

For the design of the atrium in high-rise buildings:

- Usually, it is located at the entrance where the hall/reception functional units are conceived. The atrium would impact vertically more levels to improve micro-climate, exploiting natural air ventilation due to chimney effect (it should be connected helicoidally with other levels). Such as the atria in Mary Axe designed by Foster and Partners in UK.
- The dimensions of the atrium can privilege the predominance of the chimney effect or the greenhouse effect. In fact, if the dimensions are contained, air velocity is improved, and the chimney effect is predominant.

To conclude, it is advisable to highlight that the design of the atrium should be combined with the window-to-wall ratio design. For instance, in the Commerzbank (designed by Foster and Partners) the atrium combined to glazing façade (usually double skin façade) and green area is used in different level of the building to ensure right microclimate conditions.

Some design criteria aimed at reducing the cooling demand of the building during summer season are shown below.

- Usage of solar shading system to regulate solar radiation and natural lighting inside the environment, avoiding overheating and preventing glare in workstations, especially for offices with high value of WWR. The regulation of the solar radiation can be achieved also with the geometry of the building façade such as Vodafone Headquarters (designed by Barbosa & Guimarães Arquitetos, Oporto, Portugal, 2009).
- Adopt passive cooling strategies exploiting natural ventilation to ventilate and cool the internal environment to prevent overheating and excessive use of mechanical systems.

  The passive cooling strategies can be classified as: microclimate cooling, geothermal cooling, evaporative cooling and radiative one. In the offices the most recurrent one is the microclimate cooling: comfort ventilation, free cooling, or structural cooling. These passive strategies are strictly related to the windows design (obviously based on the intended use of the buildings), the prevailing winds direction (to improve cross ventilation), the structural solutions adopted and the internal partitions design.

  Specifically, there are many ways to guarantee passive cooling in offices:

  - Solar chimneys such as the one of 115 m in the Hydro Place designed by Kuwambra Payne McKenna Blumberg architects in Manitoba (CA) in 2009. This building receives the LEED Platinum environmental-energy certification with energy needs lower than 85 kWh/yr.

- Water tubs to guarantee evaporative cooling such as in the atrium of the International Federal Agency. In this case the air is cooled by evaporating water and the strategy better performed in climate characterized by relative humidity lower than 30%.
- Indirect free cooling exploiting the soil to cool air or water before enters the building functional areas. This strategy is still used in the building of the International Federal Agency.

It is worth noticing that for guaranteeing proper air change rate in buildings with this intended use it is important obviously to install mechanical ventilation systems. The mixed-mode systems are usually needed for ventilation and conditioning and so combining passive cooling and colling systems. In this case to save energy and control real internal conditions in terms of both concentration of pollutants and internal thermal-hygrometric conditions to activate ventilation, an automated monitoring is necessary (such as BACS – Building and Automation Control System).

Design Strategies to Reduce Emissions of Greenhouse Gas

Such as in residential building the main strategy to reduce the emissions is producing energy exploiting renewables. The integration of PV system in office buildings is recurrent and there are 4 possible configurations:

- Overcladding (cool roof or façade): the PV system creates the external layer of the roof/façade. This is the case of Buhler Electricitè Office, Kurmann & Cretton SA, Monthey (Switzerland), 2008-2011.
- Enclosure (warm roof or façade): the PV system are installed on usual glazing system. For instance, the Autobrennero A22 Office, Studio Associato Giovannazzi, Trento (Italy) 2009.
- Shading devices: the PV system are arranged on the solar shading system choose for the building. An example of this PV system installation is the FEAT Headquaters, Claudio Lo Riso, Lugano (Switzerland), 1997.
- Glazing roof: in this case the PV system is installed on the glazing roof of the building. A representative case of this design choice is Vovartis Campus Gehry Building, Gehry & Partners Ltd, Basel (Switzerland), 2008.

Other strategies, as for residential buildings, are:

- The usage of materials according to CAM (Minimum Environmental Criteria). Building components must be made of natural materials or those ones that include a precise percentage of recycled materials.
- The management of natural and artificial lighting is fundamental to save energy. Specifically, automated control system to control daylighting intensity and brightness of the workplace are highly recommended.

Building Orientation

Solar radiation is the main driver for the proper orientation of the building more than the prevailing winds direction. This is proved by the assumption that winds are more difficult to control. However, it is possible to adopt natural or artificial barrier to deviate and mitigate wind actions; as example rotating the building with the main axis perpendicular to the prevailing winds direction (if it is applicable, for instance if the shape of the construction site allows it).

With respect to solar radiation the best orientation for an office building is with main axis on East-West direction. Thus, to exploit solar gains and to better control the solar radiation inside the building to prevent overheating or glare issues. In detail:

- For low-rise offices: if the floor plan is a rectangle, it should develop along East-West axis, as explained before. This orientation can be changed of a small angle equal to +/– 15°. This slight rotation does not influence the energy performance of the building. If the floor plan is a square, the rotation of 45° with respect to North-South axis is recommended to avoid disadvantageous exposition for workstations. In this case, a specific study on shading devices is needed.
- For high-rise offices: in this case the prevailing winds mostly affect the orientation and the position of the building. This occurs for 2 different reasons: the horizontal forces on the load-bearing structure and the exploitation of natural ventilation for cooling. The recommended shape for the floor plan is the circular one.

Geometry of the Building: Floor Plan Layout and Functional Distribution

For offices, 3 main recurring types of configurations can be represented (Fig. 3.15):

- High-rise type with compact shape of the floor plan (A). This is a 12-storey building with a polar symmetry of the floor plan. The floor plan is characterized by a squared shape with about 24 m side. Services (ex. toilets, vertical connections, etc.) are developed in the center of the square and a horizontal connection links all office working areas.
- High-rise type with linear shape of the floor plan (B). This is a 12-storey building characterized by a linear shape with main dimensions 12 m x 48 m. Services are grouped in the center of the building and a horizontal connection link the different office working area developing on both sides.
- Low-rise type with internal open courtyard (C). This is a 4-storey building with main dimensions of the floor plan equal to 36 m x 60 m. The open central courtyard is characterized by linear shape (12 m x 36 m). Services are grouped in eastern and western front to leave the offices arranged in the most advantageous orientations (Miceli, 2013).

In the following Table 3.2 the geometry characterization of the different office building type is shown for completeness. Regarding to the dimensioning of the floor plan (A, B, C), a surface of 15.5 m^2 for each single worker are considered. The number of workers is equal to 446. In Table 3.2 the first 6 lines are related to the parameters distinguishing the floor plan of the building, while the remaining the characteristics of the whole building.

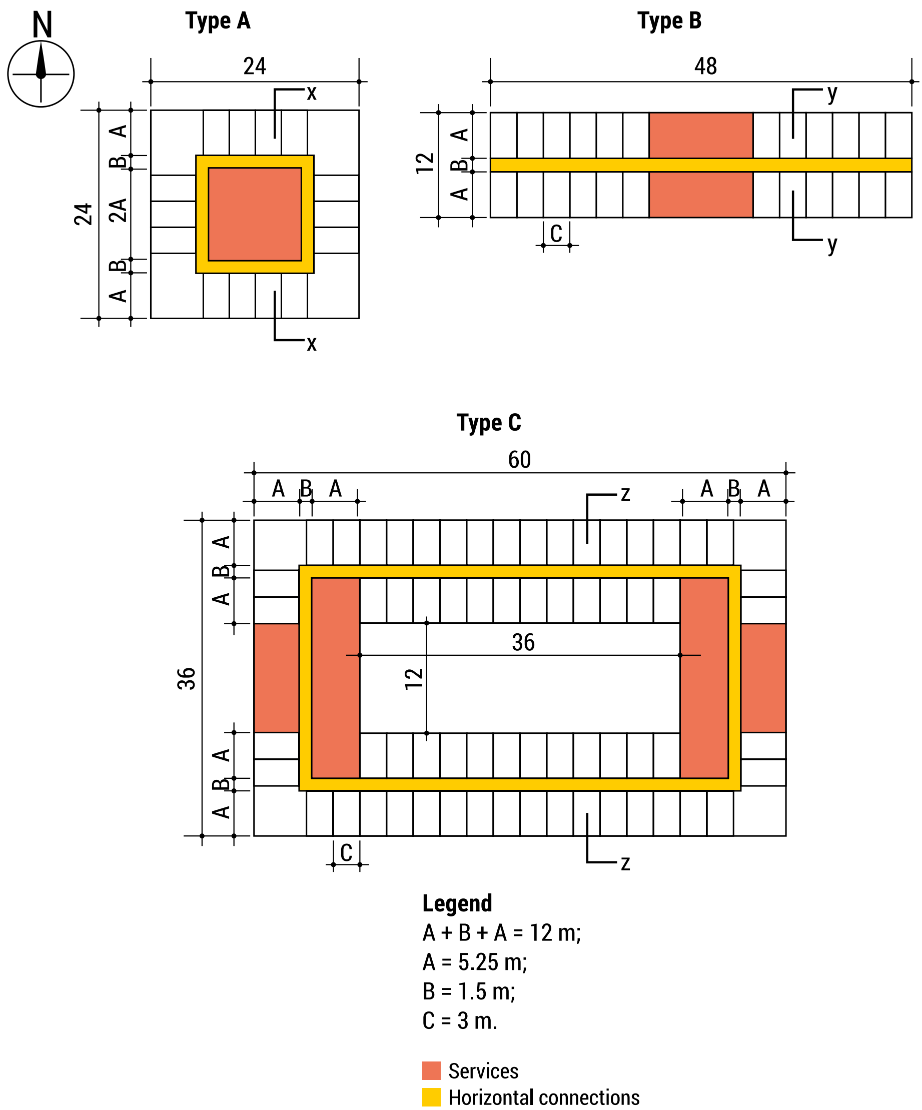


FIG. 3.15. Some possible geometries (A, B, C) for a sustainable office building with the indications of the main dimensions and services and horizontal connection functional bands (Source: own elaboration based on Miceli, 2016)

The functional macro-zones of an office building are the following ones:

- Working area as cellular space, open space, combination of both (primary functional area). It can be considered the primary functional area.
- Horizontal and vertical connections as stairs, elevators and corridors.
- Area for services. For instance: reception, meeting rooms, library, break and relax area, toilets, storage, etc. It can be considered the secondary functional area.

TABLE 3.2. Geometry characterization of the floor plan of the different type of outlined office buildings with the indication of aspect ratio, main dimensions of the floor plan (a, b), sizes of the courtyard (c, d), gross area of the floor plan (A_{FP}), number of levels (N_L), total height of the building (H_{tot}), total gross area of the building (A_T), volume of the building (V), number of workers (N_w), A/V ratio (Source: Miceli, 2016)

Type	A	B	C
Aspect ratio	a:b = 1	a:b = 4	a:b = 1.6 c:d = 3
a [m]	24	48	60
b [m]	24	12	36
c [m]	–	–	36
d [m]	–	–	12
A_{fp} [m^2]	576	576	1728
N_L	12	12	4
H_{tot}	48	48	16
A_T [m^2]	6912	6912	6912
V [m^3]	27648	27648	27648
N_w	446	446	446
A/V ratio [m^{-1}]	0.21	0.25	0.29

The following Table 3.3 shows some representative dimensions, related to each function, recommended for a sustainable office building. This size ensures workers well-being during working time. Sizes are deduced from environmental system analysis of several sustainable office buildings and some reference in literature (Arredi, 2004) by averaging.

TABLE 3.3. Square meters for person for the main functional zones and macro-zones of sustainable office buildings (Source: Miceli, 2016). It is worth to notice that the Italian manuals suggest from 5 m^2 – to 10 m^2 for person. Italian regulations minimum is 5 m^2 per person; single office minimum 9 m^2 per person. In the tables offices macro-zone includes area for the access to the workstation, area for special services and vertical and horizontal connections; services macro-zone includes all the secondary functional units that support the office

Space requirements for office work	Space adopted [m^2/pers]	Macro-zones [m^2/pers]
Work station area	7.5	OFFICES: 10.8
Area for access to the work station: internal circulation	8.3	
Are for special services: meeting rooms, showing rooms etc...	10.8	
Vertical and horizontal connections	12.4	SERVICES: 4.8
Area for services that support office zones: archive, break area, toilets, etc...	15.5	

Structure

Vertical load-bearing structure

The most recurring structural solution for a low-rise sustainable office building in Italy, is the reinforced concrete load-bearing structure. While for the high-rise one is the mixed one (combining steel and reinforced concrete).

The choice of materials mainly depends on the construction local tradition, but also on availability of local materials. It is preferable to use them to reduce both economic and environmental costs as well as to verify the impact of the entire production cycle LCA (Life Cycle Assessment).

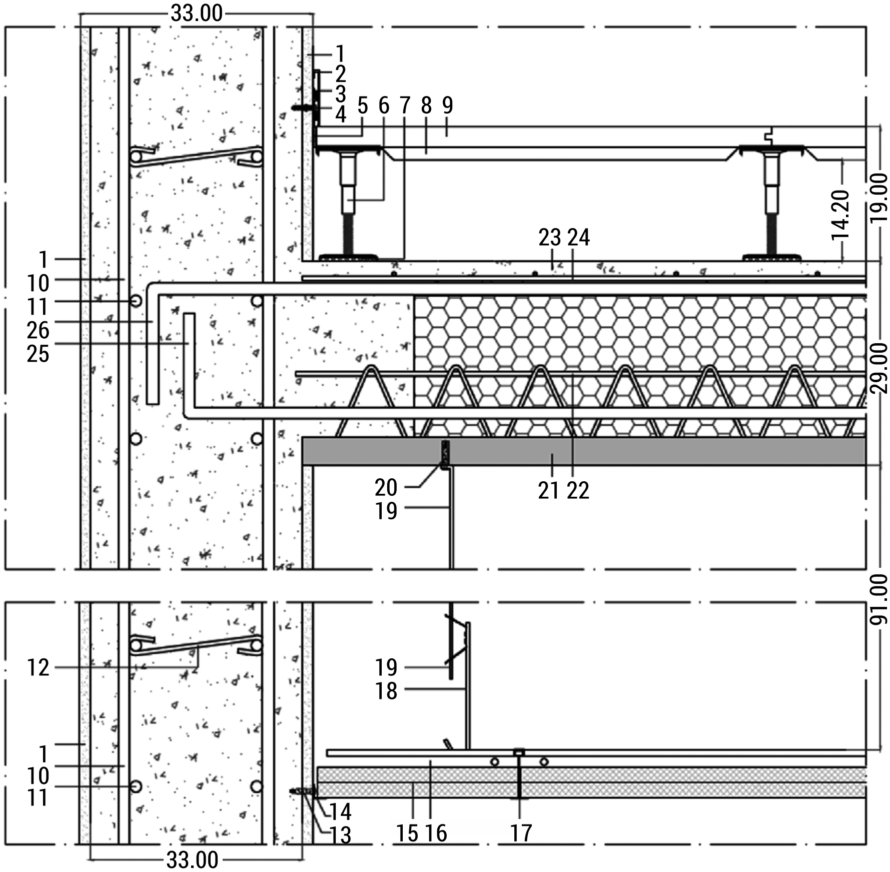
Horizontal load-bearing structure

The solution with reinforced concrete slabs is the most recommended. It should be combined with floating floor to allow electrical systems installation and improve the flexibility of internal spaces.

The solution of reinforced concrete slab without false ceiling and systems exposed could be preferable because it is economically convenient, and the floor slab would perform better as thermal mass. In fact, it ensures to store heat during winter season (solar radiation exploitation) and to cool the building during summer one (natural ventilation exploitation).

Despite in such case it is important to provide acoustic strategies to improve acoustic comfort (ex. punctual acoustic panels on the workstation).

In Figure 3.16 an alternative to the reinforced concrete horizontal slab is illustrated. The detail shows a *predalle* slab type completed with floating floor and false ceiling, both for the installation of systems. Sometimes, in the false ceiling, the radiant panels for both heating and cooling are installed.



Legend

1. Internal plaster
2. Aluminium baseboard
3. Baseboard bracket
4. Baseboard dowel
5. Elastic joint
6. Floating floor substructure
7. Acoustic insulation
8. Floating floor horizontal substructure
9. Floating floor panel
10. Vertical Reinforcement
11. Horizontal Reinforcement
12. Pins
13. Dowel for fixing L-shape false-ceiling board profile
14. L-shape false-ceiling board profile
15. False ceiling plasterboard panel
16. False ceiling main substructure, T-shape
17. False ceiling secondary substructure, L-shape
18. False ceiling Suspension hook
19. False ceiling Pendant
20. Dowel
21. Predalles floor slab
22. Predalles floor slab
23. Concrete slab for floor slab with internal reinforcement (24)

25.-26. Linking reinforcement

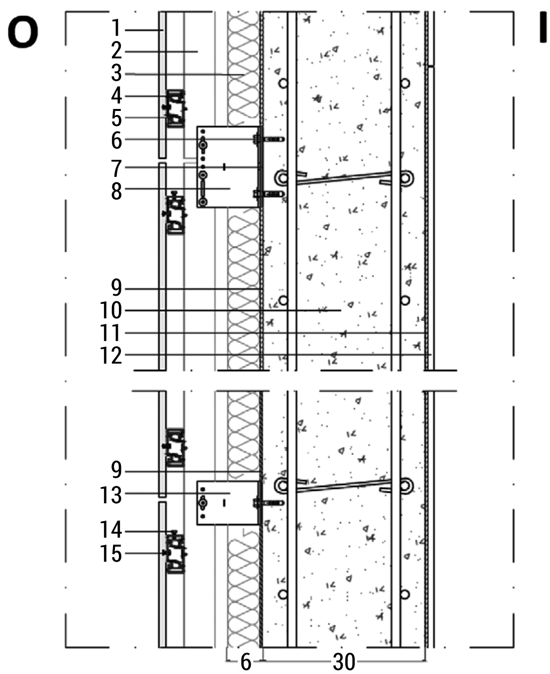
FIG. 3.16. Possible floor slab detail with predalles type solution completed with floating floor and false ceiling (Source: own elaboration)

Technological Solutions for the Building Envelope

External wall

The most recurring solutions for the external envelope are:

- Lightweight bricks for load-bearing layer with gypsum plaster as internal finishing, an external EPS insulation layer (thickness depends on climate zone and systems used for heating and cooling), rainscreen façade with aluminum substructure and several types of external finishing that are available on markets (aluminum panels, ceramics tiles etc.…). Sometimes they become ventilated façades as well. Figure 3.17.
- Glazing external wall (usually regardless orientation), using double skin façade or simple curtain wall. In this scenario, a specific attention to the type of glazing according to the climate and the orientation should be provided.



Legend
(outside-inside)

1. Cladding panel
2. Aluminium vertical sub-structure
3. Thermal insulation
4. Aluminium horizontal sub-structure
5. Clip
6. Dowel
7. EPDM thermal break
8. L-shape bracket
9. Adhesive
10. Reinforced concrete structure
11. Adhesive for external cladding
12. Internal finishing
13. C-shape bracket

FIG. 3.17. Possible technological solution with rainscreen façade and lightweight external finishing applied on a reinforce concrete load-bearing structure (Unipol Tower, Italy) (Source: own elaboration)

Airtightness of the envelope must be guaranteed to ensure proper internal thermal conditions.

For both cases PV panel should be integrated in the façade. For the first solution, PV panels disposed on the parapet should be preferable. It can be also sloped to improve the electricity production.

For the second solution, PV panels can be integrated into the transparent façade also creating a solar radiation protection.

As regard the thickness of insulation some considerations are needed.

The optimum thickness of insulation material depends on the answer to the question if it is economically convenient increasing the thickness of the insulation on the envelope or heating and cooling trough systems.

This answer is impacted through several parameters: climate conditions (heating dree-days – HDD and cooling degree-days CDD); composition of the external wall (ex. insulation type and its thermal properties); type of systems; type of energy source; costs of both material and the energy source.

In the following Table 3.4 the optimum thickness of insulation (looking at costs) is shown with respect to possible range of HDD (in this case according to current Italian standard) and 2 different types of system:

- System 1: condensing gas boiler (efficiency equal to 0.9) for both heating and service hot water and air conditioning system (seasonal performance factor equal to 2) for cooling and fan coils as terminals. The sources are gas and electricity.
- System 2: reversible heat pump (Heat Pump and Compression Chiller) for heating (COP = 3), cooling (COP = 2) and service hot water fan coils as terminals. The sources are both electricity and renewables.

TABLE 3.4. Optimum thickness of insulation for the envelope of an office building considering EPS insulation material with common thermal properties (λ=0.032 W/mK) considering 2 different type of system. In the table $T_{i,opt}$ means the thickness of insulation [cm] and $U_{i,opt}$ stands for thermal transmittance [W/m^{2}K] (Source: Miceli, 2016)

Heating Degree Days	System 1		System 2	
[kd/y]	$T_{1,opt}$ [cm]	$U_{1,opt}$ [W/m^{2}K]	$T_{2,opt}$ [cm]	$U_{2,opt}$ [W/m^{2}K]
600 < HHD < 900	7	0.26	6	0.29
900 < HHD < 1400	8	0.24	7	0.26
1400 < HHD < 2100	10	0.21	8	0.24
2100 < HHD < 3000	12	0.19	10	0.21

Roof

Roof could be opaque to permit preferably the installation of PV systems, or it can be a green roof. In the last case the roof stratigraphy become a passive strategy to improve the thermal indoor comfort.

If the office building has an atrium, the roof can be made by glazing openable elements (skylights) to permit natural ventilation and night cooling.

Glazing

Here below three examples of glazing adopted especially in Southern countries.

- Glass type 1: 6 mm Pyrolitic Clear Glass + 16 mm Argon + 44.2 laminated glass with PVB interlayer; properties: LSG=1.12, SHGC=0.63, VT=0.71, U=1.7 W/(m^2K).
- Glass type 2: 6 mm Spectral Selective Glass + 16 mm Argon + 44.2 laminated glass with PVB interlayer; properties: LSG=1.63, SHGC=0.41, VT=0.67, U=1.37 W/(m^2K).
- Glass type 3: 6 mm Low-e Spectral Selective Glass + 16 mm Argon + 44.2 laminated glass with PVB interlayer; properties: LSG=2.04, SHGC=0.24, VT=0.49, U=1.01 W/(m^2K).

Where: LGS stands for Light to Solar Gains ratio, SHGC means Solar Heat Gain Coefficient, VT is Visible Transmittance and U stands for thermal transmittance.

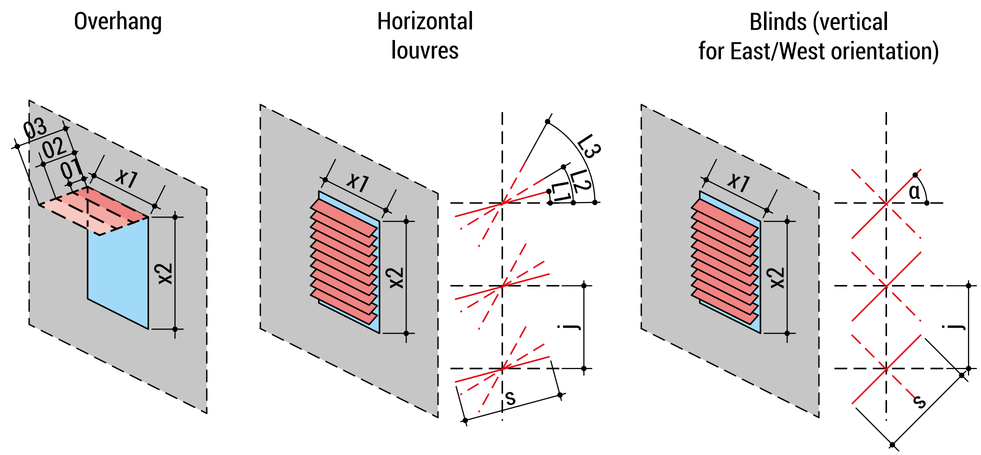
Window-to-Wall Ratio

The design of the WWR parameter is fundamental (especially for those buildings characterised by curtain wall for most facades, regardless orientation), for the following reasons:

- It affects ad regulates the natural lighting within the offices functional units and can permit the optimization of the artificial lighting that is one of the main energy consumption.
- It permits the control of the solar radiation. For instance, WWR with higher values permit the reduction of the heating demand, while WWR with lower values reduce the overheating and the cooling demand.

In order to give proper recommendations about the adoption of WWR and to calculate how this solution impact on the energy demand of the building; different parameters are considered: climate conditions, different types of glasses (as detailed in the previous paragraph), the typology of solar shading devices (overhang or horizontal louvres for South orientation and vertical blinds for East/West orientations with high or low reflectance) (Fig. 3.18), the type of system (system 1 and system 2 as explained before) and the final energy demand.

It is worth to notice that for North orientation shading devices are not recommended.



01 = 0.50 m;
02 = 1.00 m;
03 = 1.5 m;
x1 and x2 vary according to WWR

L1 = 15°;
L2 = 30°;
L3 = 60° (fixed during year);
s = 0.30 m;
l = 0.15 m;
x1 and x2 vary according to WWR

0° < α < 180° during the year;
s = 0.30 m;
l = 0.15 m;
x1 and x2 vary according to WWR
M/H = Medium/High reflectance

FIG. 3.18. Different type of solar shading systems and related characteristics considered to recommend the advisable WWR for designing sustainable office buildings (Source: own elaboration based on Miceli, 2016)

The advisable solutions for WWR are detailed in the following Figure 3.19 considering 3 different cities belonging to different Italian climate zones:

- Milan (2100 < HHD < 3000 Kd/y).
- Florence (1400 < HHD < 2100 Kd/y).
- Palermo (600 < HHD < 900 Kd/y).

In the tables the colours green/yellow/red idientify the STRONGLY, LESS and NOT recommendeable actions. The different colours are outlined on the base of the difference (D) between the final energy demand of the considered solution and the one of the best configuration:

- STRONGLY: D < 5 kWh/(m^2year) – (+).
- LESS: 5 kWh/m^2year < D < 10 kWh/(m^2year) – (-).
- NOT: > 10 kWh/(m^2year) – (0).

Milan

System 1

South
Overhang

WWR	O1	O2	O3
20%	+	+	–
30%	+	+	+
40%	+	+	+
50%	–	+	+
60%	0	–	+
70%	0	–	–
80%	0	0	0
90%	0	0	0
100%	0	0	0

South
Horizontal Louvres

WWR	L1	L2	L3
20%	–	0	0
30%	–	0	0
40%	–	0	0
50%	+	–	–
60%	+	+	+
70%	+	–	–
80%	–	–	–
90%	0	0	0
100%	0	0	0

East
Vertical blinds

WWR	MVB	HVB
20%	–	+
30%	–	+
40%	–	+
50%	–	+
60%	0	+
70%	0	–
80%	0	0
90%	0	0
100%	0	0

West
Vertical blinds

WWR	MVB	HVB
20%	–	+
30%	–	+
40%	–	+
50%	0	+
60%	0	–
70%	0	0
80%	0	0
90%	0	0
100%	0	0

System 2

WWR	O1	O2	O3
20%	–	–	–
30%	–	+	–
40%	+	+	+
50%	–	+	+
60%	0	–	+
70%	0	0	–
80%	0	0	–
90%	0	0	0
100%	0	0	0

WWR	L1	L2	L3
20%	0	0	0
30%	0	0	0
40%	–	0	0
50%	+	–	–
60%	+	+	+
70%	+	+	+
80%	–	–	–
90%	0	0	0
100%	0	0	0

WWR	MVB	HVB
20%	0	–
30%	–	+
40%	–	+
50%	–	+
60%	–	+
70%	–	+
80%	0	–
90%	0	–
100%	0	0

WWR	MVB	HVB
20%	0	–
30%	0	+
40%	–	+
50%	–	+
60%	–	–
70%	–	0
80%	0	–
90%	0	–
100%	0	0

Florence

System 1

South
Overhang

WWR	O1	O2	O3
20%	+	–	–
30%	+	+	–
40%	+	+	+
50%	–	+	+
60%	0	+	+
70%	0	–	–
80%	0	0	–
90%	0	0	0
100%	0	0	0

South
Horizontal Louvres

WWR	L1	L2	L3
20%	0	0	0
30%	0	0	0
40%	–	0	0
50%	+	–	–
60%	+	+	+
70%	+	+	+
80%	–	–	–
90%	0	0	0
100%	0	0	0

East
Vertical blinds

WWR	MVB	HVB
20%	–	–
30%	–	+
40%	–	+
50%	–	+
60%	–	+
70%	0	–
80%	0	–
90%	0	–
100%	0	0

West
Vertical blinds

WWR	MVB	HVB
20%	0	–
30%	–	+
40%	–	+
50%	0	+
60%	0	+
70%	0	–
80%	0	–
90%	0	0
100%	0	0

System 2

WWR	O1	O2	O3
20%	–	–	–
30%	–	+	+
40%	+	+	+
50%	–	+	+
60%	0	–	+
70%	0	0	–
80%	0	0	0
90%	0	0	0
100%	0	0	0

WWR	L1	L2	L3
20%	0	0	0
30%	0	0	0
40%	–	0	0
50%	+	–	–
60%	+	+	+
70%	+	+	+
80%	–	–	–
90%	0	0	0
100%	0	0	0

WWR	MVB	HVB
20%	0	–
30%	–	+
40%	–	+
50%	–	+
60%	–	+
70%	–	+
80%	0	–
90%	0	–
100%	0	–

WWR	MVB	HVB
20%	0	–
30%	0	+
40%	–	+
50%	–	+
60%	–	+
70%	–	+
80%	0	–
90%	0	–
100%	0	0

Palermo

System 1

	South Overhang			South Horizontal Louvres			East Vertical blinds		West Vertical blinds	
WWR	O1	O2	O3	L1	L2	L3	MVB	HVB	MVB	HVB
20%	+	+	+	–	–	0	0	–	0	0
30%	–	+	+	+	–	0	0	+	0	–
40%	0	+	+	+	–	–	0	+	0	+
50%	0	–	+	+	+	+	0	+	0	+
60%	0	0	–	+	+	+	0	+	0	+
70%	0	0	0	0	–	–	0	–	0	–
80%	0	0	0	0	0	0	0	–	0	–
90%	0	0	0	0	0	0	0	0	0	0
100%	0	0	0	0	0	0	0	0	0	0

System 2

	South Overhang			South Horizontal Louvres			East Vertical blinds		West Vertical blinds	
WWR	O1	O2	O3	L1	L2	L3	MVB	HVB	MVB	HVB
20%	+	+	+	–	–	0	0	–	0	0
30%	–	+	+	+	–	0	0	+	0	–
40%	0	+	+	+	–	–	0	+	0	+
50%	0	–	+	+	+	+	0	+	0	+
60%	0	0	–	+	+	+	0	+	0	+
70%	0	0	0	0	–	–	0	–	0	–
80%	0	0	0	0	0	0	0	–	0	–
90%	0	0	0	0	0	0	0	0	0	–
100%	0	0	0	0	0	0	0	0	0	0

FIG. 3.19. Advisable WWR ratio for Milan, Florence e Palermo considering different types of glass, system, and shading devices (Source: own elaboration based on Miceli, 2016)

Systems and Renewables

For sustainable office buildings two configurations of systems are summarized: the first one (System 1) is a traditional solution, the second one (system 2) the most efficient:

- *System 1*: condensing gas boiler (efficiency equal to 0.9) for both heating and service hot water and air conditioning system (seasonal performance factor equal to 2) for cooling and fan coils as terminals. The sources are gas and electricity respectively.
- *System 2*: reversible heat pump (Heat Pump and Compression Chiller) for heating (COP=3), cooling (COP=2) and service hot water fan coils as terminals. The sources are both electricity and renewables.

Both configurations should be integrated with a monitoring system to manage and save energy for both heating and cooling. Therefore "System 2" is the most common and more recent system configuration and it permit the reduction of CO_2 since the exploitation of renewables.

As regard active strategies, PV panels are the most recommended to partly cover the electricity demand. According to different geometries (type A, B, C) it is possible to dispose PV system in several different configurations:

- On the roof (flat or sloped).
- On southern façade (ex. vertical position, entire sloped façade, sloped only the parapet, applied on solar shading systems).

It is worth to notice that to maximize electrical energy production:

- For high-rise office buildings (A rectangular or B square floor plan): PV panels should be disposed in a roof (both flat and sloped) and mainly positioned in the Southern façade that should be sloped.
- For low-rise office buildings: with internal courtyard (C) the best energy performance of the building is achieved with PV systems installed on the sloped roof and on southern façade that should be sloped.

With respect to lighting system the use of high-performance lamps (light power density equal to 8 W/m^2) is recommended as well as automatic daylight harvesting control and occupancy sensors.

Footnotes

[1] "Global Warming Potential (GWP) is defined as the cumulative radiative forcing, both direct and indirect effects, over a specific time horizon resulting from the emission of a unit mass of gas related to some reference gas (CO_2)." (Source: Iyyanki V. Muralikrishna,Valli Manickam (2017) Chapter Fourteen – Air Pollution Control Technologies, *Environmental Management*, pp. 337-397)

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