Definition of a reference office building for simulation based evaluation of solar envelope systems

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Abstract

Solar Envelope systems, which represent the technological response for meeting aesthetic requirements and solar renewable energy exploitation on building façades, are gaining rising attention. However, they are still rare on the market. IEA SHC Task 56 focuses on the critical analysis, simulation, laboratory tests and onsite monitoring of market available and near market Solar Envelope systems. Within this framework, reference boundary conditions are required in order to assess the performance of Solar Envelope systems and compare different technologies through numerical simulations.

The present paper reviews the process of defining reference boundary conditions for an office building, listing possible simplifications and required assumptions in order to calculate the impact at whole building level in terms of useful and final energy savings related to the installation of a façade integrated technology. The paper concludes with a comparison of simulation results between TRNSYS and DALEC, a simplified concept evaluation tool, which performs combined thermal and lighting analysis already at early design stages.

Keywords: Solar energy; Building façade; IEA

1. Introduction

In both residential and tertiary (offices, schools, hospitals) building sectors, solar thermal and PV systems are typically mounted on building roofs with limited attempt to incorporate them into the building envelope, creating aesthetic drawbacks and space availability problems. Building integrated solutions of respective technologies (typically referred as BIST and BIPV) are the technological response for meeting aesthetic requirements and solar renewable energy exploitation.

Daylighting control deeply influences visual and thermal comfort, electrical consumption for lighting as well as heating and cooling loads in buildings. Most of the time, solar control is delegated to individuals' management of internal and external blinds, even though smart lighting controls are nowadays state of the art in particular for the tertiary building sector.

Building integrated solar thermal and PV technologies and daylighting solutions are part of the so-called Solar Envelope systems, which entail elements that use and/or control incident solar energy, having one or more of the following uses:

- To deliver renewable thermal or/and electric energy to the systems providing heating, cooling and ventilation to buildings;
- To reduce heating and cooling demands of buildings, while controlling daylight.

IEA SHC Task 56 focuses on the critical analysis, simulation, laboratory tests and onsite monitoring of market available and near market Solar Envelope systems (http://task56.iea-shc.org/). The strategic objective is to coordinate the research and innovation efforts taking place within the scientific community and the private sector.

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In particular within subtask C, complete Solar Envelope systems are defined based on active and passive components and integrated into the HVAC system of reference buildings. These buildings are considered as virtual case studies, in which specific envelope elements are integrated into.

The performance assessment (in terms of thermal, electric and daylighting behavior) of Solar Envelope elements by means of building and HVAC simulations is key for supporting decision-making processes in a techno-economic perspective. The comparison of multiple technological solutions should be carried out under the same boundary conditions such as reference climate datasets, user patterns (occupancy profiles), thermal and visual comfort requirements, building geometry and characteristics. The model can be used as a baseline for comparative studies, product rating or educational purposes. Therefore, it is important to find an agreement on a common definition of reference boundary conditions that covers at least a wide range of applications.

The aim of the paper is to provide a detailed description of boundary conditions to adopt for the transient simulation of a reference office building, that enables yearly performance evaluation of different solar active façade technologies. Although TRNSYS software is the tool used for simulation purposes, the description of the reference office boundary conditions aims to be platform independent and to be flexible enough allowing energetic, thermal and daylighting calculations. Most of the times, these tools are too demanding for façade designers and architects and therefore simplified tools are more than welcome. In order to ease the assessment of Solar Envelope systems by means of numerical simulations, within the framework of IEA SHC Task 56 simplified design tools are analyzed. For this purpose, DALEC (Werner et al., 2017), a simplified on-line tool that assesses thermal and daylighting performances of a user-defined façade design, is one of the tools here evaluated.

2. Definition of the reference zone and weather analysis

2.1. Reference climate

Three reference climatic conditions are selected for simulation purposes: Stockholm (Sweden), Stuttgart (Germany) and Rome (Italy) are chosen as they portray a significant range of European climatic conditions. The weather dataset used for simulation purposes is generated using the Meteonorm 7 database and contains hourly values of meteorological parameters such as ambient air temperature, humidity and solar radiation for a one-year period. For comparison purposes, Table 1 shows the following annual climatic parameters for the three locations. The Mediterranean climate is relatively warm with an annual average ambient temperature around 16 °C whereas colder climates and higher annual temperature amplitudes are experienced at higher latitudes with especially harsh winters in Stockholm. The annual average relative humidity is instead rather constant among the three climates. The annual solar irradiation decreases with the latitude and is lower on vertical facades than on the horizontal in all climates. The annual solar irradiation is higher for South-oriented façades in comparison to other orientations and varies between 1251 kWh/(m^2y) in Rome and 894 kWh/(m^2y) in Stockholm.

2.2. Definition of the reference zone

Because of the potentially high computational efforts, the energy analysis of high-rise office buildings by means of transient simulations needs adequate simplifications in the development of a numerical model. Since the aim of Subtask C of IEA SHC Task 56 is to carry out an analysis on the energy contribution of different solar active façade technologies in covering building loads and to evaluate indoor comfort conditions, the definition of a detailed architectural building geometry is of less importance. Thus, simplifications and assumptions on building geometry and user behavior are necessary and a good trade-off between accuracy of the model and computational and results analysis efforts has to be found. The reference zone is chosen considering the elementary and most representative modulus of this kind of structures that is a generic office localized in a mid-floor of a high-rise building.

Several attempts in the scientific community have dealt with the definition of reference office buildings (Reinhart et al., 2013; Deru et al., 2011). Geometric and thermophysic properties of the façade and boundary conditions (as internal gains or occupancy profile) are typically functional for the purpose of the simulation analysis to be conducted. When adopted for a simulation analysis that differs from the original scope, users can experience limitations in implementing their desired conditions and need to introduce assumptions that impede a straightforward comparison.

In order to benchmark a Solar Envelope system against a competing technology, the reference office zone could require some adaptation. For example, changes could involve the design of the façade assembly (e.g. WWR) or numerical aspects (e.g. simulation time step). In principle, this is possible, but it is requested to include results for the reference set of boundary conditions here presented.

A typical office cell as the one shown in Figure 1 is considered as reference thermal zone. The reference office cell is 6.0 m long, 4.5 m wide and 3.0 m high, resulting into 27 m^2 floor surface and 81 m^3 gross air volume. The facade is composed of three façade modules with a 60% window-to-wall ratio (gross value including façade frame), each of which is constituted by a lower spandrel panel and a non-openable window. The office zone is unobstructed from neighborhood buildings. It is assumed that internal walls, floor and ceiling do not exchange heat with adjacent zones, whereas the sole façade is exposed to the exterior environment. Although solar technologies can be theoretically integrated in facades with any azimuthal orientation, the South-oriented facade is considered for reference purposes, as it is the one most commonly exploited for solar applications.

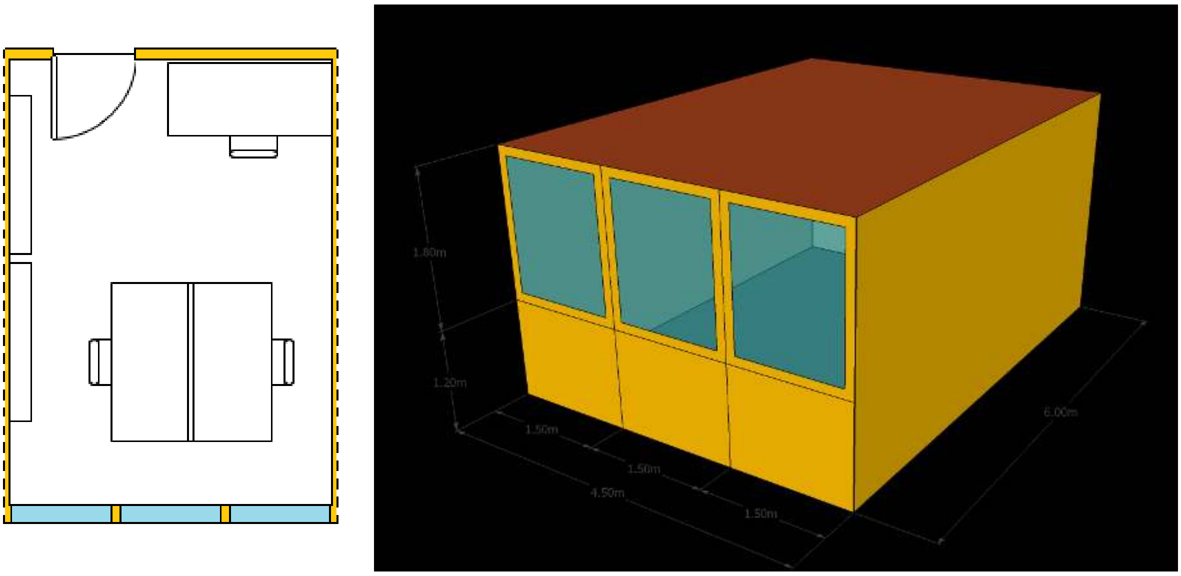

Fig. 1: View of the reference office zone.

The reference zone is modelled with a single-zone single-air node model and a set of parameters is used to characterize the office space in terms of occupancy, internal gains, ventilation, infiltration rate and shading. The optical and thermal properties of the building assemblies as well as the most relevant boundary conditions are listed in Tables 2-7. Envelope characteristics are varied for the different locations, but it should be pointed out that these boundary conditions do not aim to define a building typology for the three reference locations nor a reference energy use for tertiary office buildings.

Fresh air is supplied through a centralized mechanical ventilation system, to which a specific fan power of 0.55 Wh/m^3 is assigned. The ventilation unit is further equipped with a heat recovery unit with a sensible efficiency of 70% (SIA 2024, 2015), a by-pass strategy and a frost protection by means of an electrical resistance.

The delivery of heating and cooling to the reference office zone is distinguished between air- and water-based emission systems and for both cases sizing criteria and control strategies of the emission system are specified. As reference heating and cooling generation systems, a gas boiler and an electrically driven chiller are considered. Both are assumed to be centralized at building level. Since cooling and heating are in principle possible simultaneously throughout the year, the definition of an annual schedule for switching on and off single units is not necessary. The computation of final energy is carried out using average yearly coefficients of performance, but specifications of these aspects are still to be debated within the IEA SHC Task 56. For an exhaustive description of the boundary conditions and a more detailed description of the modelling approach, the reader is invited to refer to the IEA SHC Task 56 Subtask C activities.

2.3. Simplification of model inputs and parameters for DALEC simulation

DALEC (Day- and Artificial Light with Energy Calculation) is an online concept evaluation tool for architects, building engineers, lighting designers and building owners. Although it is easy to use and has short calculation times, the software accounts for the complex thermal and light processes in buildings and allows a simple evaluation of heating, cooling and electrical lighting loads. This allows optimizations of the façade settings, the artificial lighting installation and the thermal parameters of a building in an early design phase.

For the reduced inputs into DALEC, the relevant parameters need to be derived from the specified boundary conditions of Appendix I. The following simplifications from TRNSYS to DALEC are necessary:

- Occupancy, appliances and fan power need to be summarized as internal gains. Calculating the gains according to the schedules given in Table 2 of Appendix I, it results in 9.74 W/m^2 of internal gains over the 11 hours of overall occupancy time from 08:00 to 19:00.
- In DALEC, the transparent area of the façade is defined as relative fraction of the overall façade in three areas. In the lower area (below 1 m) no transparent structure is present. For the middle are (1 m - 2 m height) the window size as defined in paragraph 2.2 starting at 1.20 m height and with 11 cm frame translates into 0.59 active window area, while for the upper area an active area of 0.76 is obtained.
- Two air exchange rates are considered in DALEC. The general energy-equivalent air exchange rate is the sum of infiltration and energy-effective air exchange rate in terms of ventilation losses. This rate is applied 24/7. The window / night ventilation air exchange rate assumes an additional passive ventilation whenever the indoor temperature exceeds a given threshold and is higher than the outdoor temperature. This strategy also operates the whole day (and not only during occupancy times).
- According to Table 3, the shading device is activated whenever the direct solar radiation incident on the façade exceeds 120 W/m^2. However, in the standard DALEC implementation the overall radiation incident at the façade is used for the solar shading control. To be able to compare the results from DALEC and TRNSYS, the shading control was adapted in the source code of DALEC for these simulations to match the control in TRNSYS.
- In Tables 4-7 the thermal characteristics of the opaque assemblies and building materials are given. The setup matches with a typical medium construction. Thus the value of 165 kJ/(m^{2}K) is assumed.

3. Simulation results

Numerical simulations are performed using both TRNSYS and DALEC softwares. The key performance indicators presented here, focus on the energy performance of the reference office zone and aim at a preliminary comparison between simulation results calculated by TRNSYS and DALEC. Because of this reason, the following KPIs are considered: annual active space heating (Q_{HEAT}) and cooling (Q_{COOL}) energy delivery to the thermal zone; annual total electricity demand of appliances ($W_{EL,APP}$), artificial lighting ($W_{EL,LIGHT}$), fans ($W_{EL,FAN}$) and of the antifreeze resistance ($W_{EL,AF}$) in the air handling unit.

3.1. TRNSYS simulation results

Looking at the TRNSYS energy results, the annual energy flows that characterize the thermal behavior of the office zone are listed in Tables 8-10 for the three reference locations (Rome, Stuttgart and Stockholm). In this regard, the overall energy balance is given by the sum of positive energy contributions (solar gains Q_{SOL}, internal gains Q_{GINT} and active space heating Q_{HEAT}) and negative contributions (ventilation heat losses Q_{VENT}, infiltration heat losses Q_{INF}, transmitted heat Q_{TRANS} and active space cooling Q_{COOL}) and shall be equal to zero.

In colder climates, the annual space heating and cooling energy demands increase and decrease, respectively, as expected, even though such effect is mitigated by using more insulated building assemblies and glazing with high solar factor. The space heating demand ranges from 21.3 kWh/(m^{2}y) in Stockholm to 3.5 kWh/(m^{2}y) in Rome, where the space heating is barely used. Concerning space cooling, in modern office buildings it is possible to experience overheating also during mid-season, since the high internal gains cannot be easily dissipated through the well-insulated and air-tight envelope. As a consequence, the resulting space cooling energy demand is relevant also in all the considered locations and ranges from 33.3 kWh/(m^{2}y) in Rome to 23.8 kWh/(m^{2}y) in Stockholm. The internal gains do not vary with the climate (56.5 kWh/(m^{2}y)) and are mainly generated by the artificial lighting (55%), whereas ICT appliances (24%) and human presence (21%) contribute for smaller shares. The ventilation heat losses amount to a total of 20.2 kWh/(m^{2}y) in Rome, 28.4 kWh/(m^{2}y) in Stuttgart and 30.4 kWh/(m^{2}y) in Stockholm and are greatly reduced by the use of a high-efficiency heat recovery unit, which is particularly effective at higher latitudes. The solar gains are higher in Stockholm and Stuttgart than in Rome, where a solar-control coated glazing is used. The annual solar gains are 32.9 kWh/(m^{2}y) in Rome, 59.9 kWh/(m^{2}y) in Stuttgart and 58.0 kWh/(m^{2}y) in Stockholm. The energy demand for humidification ranges from 0.2 kWh/(m^{2}y) in Rome to 5.2 kWh/(m^{2}y) in Stockholm, whereas for dehumidification from 0.1 kWh/(m^{2}y) in Stockholm to 2.1 kWh/(m^{2}y). Concerning electricity, most of the annual consumption is connected to the artificial lighting system (31.3 kWh/(m^{2}y)), whereas the fans of the ventilation unit (7.0 kWh/(m^{2}y)) and appliances (13.5 kWh/(m^{2}y)) are responsible for lower shares. The antifreeze resistance integrated in the ventilation unit, which allows to avoid icing in the return section of the heat recovery unit of the ventilation system, is active only in the colder climates of Stuttgart and Stockholm (4 kWh/(m^{2}y) and 7 kWh/(m^{2}y), respectively), whereas it remains un-used in the Mediterranean climate of Rome.

3.2. DALEC simulation results and comparison with TRNSYS

The overall agreement between the simulation results is quite good, at least when similar simplified parameter sets (e.g. for internal gains, shading control etc.) are assumed. Figure 1 to Figure 3 shows a comparison between the annual space heating and cooling energy demands calculated with DALEC (dashed fill) and TRNSYS (solid fill) software. The comparison is performed in terms of space heating, space cooling and solar gains, as other energy flows (such as ventilation, infiltration or transmission losses) are not provided as output from DALEC.

Concerning internal gains, the difference between the results of the two software is limited to 6% (or 3.2 kWh/(m^{2}y)) in all climates and, more specifically, identical results are obtained for the artificial lighting gains. It should be reminded that no advanced artificial lighting control (e.g. dimming) is considered in these simulations. As concerns indoor climate control, deviations up to 30% (or 7.0 kWh/(m^{2}y)) are found for space cooling and up to 5.0 kWh/(m^{2}y) in Stockholm for space heating. The overall agreement between the annual and monthly simulation results of TRNSYS and DALEC is relatively good, in spite of the differences in the modeling detail (ventilation, thermal capacity, angular dependent solar gains).

Although the geometric and materials specifications are purposely kept as simple as possible to minimize the opportunity of inputs errors of the part of the user, when a reference zone is modelled, it is likely that deviations from target results occur. From the experience gained from the modelling and comparison of the reference case with the two software, it is also possible to state that deviations in the energy results can be due to a multitude of causes, among which:

- Different simulation inputs (different weather files, schedules, performance of components, time-step);
- Different simulation models (diverse level of detail left to the user in defining the features of their model, physical vs empirical models, different handling of radiative exchange, heat transfer equations or capacitance effects);
- Different convergence algorithms (number of iterations, order resolution of different equation/components, convergence limits and maximum tolerances);
- Different post-processing procedures (time-frame, averaging and integration operations);
- Human mistakes and different sensibility of the modeler to certain issues.

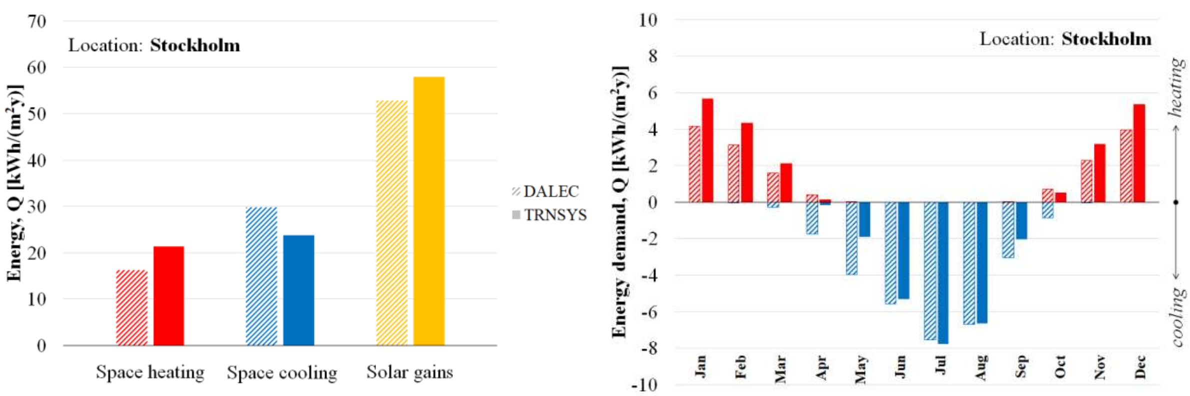

Fig. 1: Comparison of yearly (left) and monthly (right) DALEC (dashed fill) and TRNSYS (solid fill) simulation results for the reference location of Stockholm.

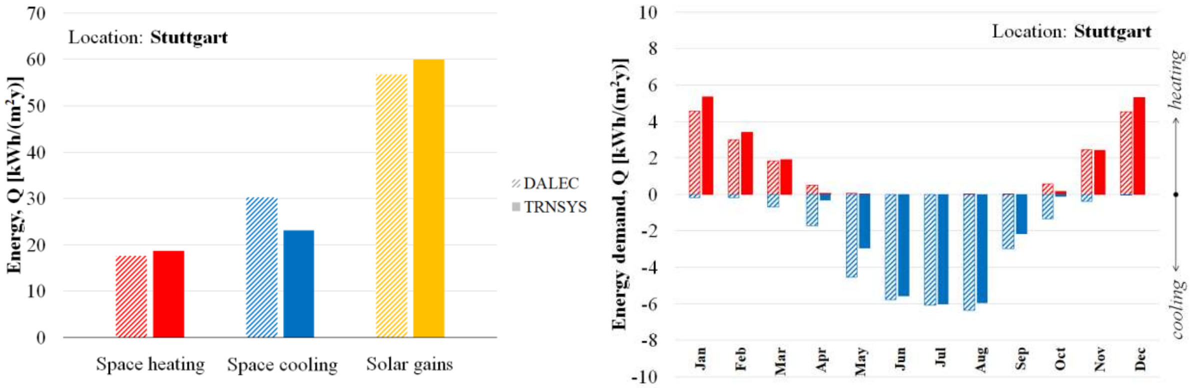

Fig. 2: Comparison of yearly (left) and monthly (right) DALEC (dashed fill) and TRNSYS (solid fill) simulation results for the reference location of Stuttgart.

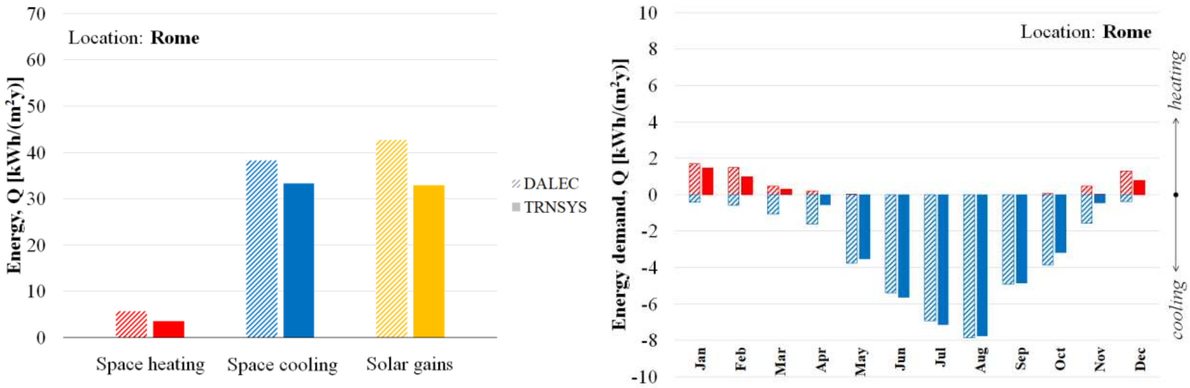

Fig. 3: Comparison of yearly (left) and monthly (right) DALEC (dashed fill) and TRNSYS (solid fill) simulation results for the reference location of Rome.

4. Conclusions

The paper focuses on the definition of a reference office zone for numerical simulation purposes of Solar Envelope systems within the framework of IEA SHC Task 56. The model description aims to be exploited by different simulation platform users and for different kind of analysis (thermal, daylighting or a combination of these).

In order to facilitate the evaluation of different Solar Envelopes systems, the adoption of simplified simulation tools is promoted. This allows overcoming typical entry-barriers (e.g. purchasing costs or learning time) in the use of high-resultion softwares. In this regard, DALEC is freely available on-line and easy-to-learn. It proves to be a reliable software to perform preliminary analysis of the energy performance of spaces characterized by simple geometries and façade designs. Undoubtedly, distinct built-in features and code structure characterize different energy simulation applications, making them more or less adequate to the scope of the user. The use of the different tools shall be then fit-to-purpose: simplified simulation software may be preferred for preliminary energy assessment of different façade designs to others that can instead handle more complex problems and may be more suitable for more expert users.

The accuracy of DALEC in predicting yearly energy performance is quite good, despite a set of simplifications in averaging hourly schedules. In the near future, the work within Subtask C of IEA SHC Task 56 will focus on the HVAC system. In high-rise buildings, heating, cooling, hot water and ventilation systems are typically centralized at building level. Façade-integrated solar technologies generate heat or electricity locally, which can be stored or consumed at the production site or shared at building scale. It is then fundamental to define a methodology to assess the impact of Solar Envelope systems on the energy balance of the building, while maintaining an adequate level of detail on the single office zones, guaranteeing thermal and visual comfort as well as indoor air quality.

5. References

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6. Appendix I: Boundary conditions for the numerical model of the reference office zone

Table 1: Average climatic parameters.

Location	Rome (Italy)	Stuttgart (Germany)	Stockholm (Sweden)
T_{amb} [°C]			
- minimum	-1.4	-12.6	-16.5
- maximum	33.1	32.4	29.7
- average	15.8	10.0	7.9
ϕ_{amb} [%]			
- average	71.9	73.5	73.4
I_g [kWh/(m^{2}y)]			
- Horizontal	1637	1105	954
- East	1251	897	894
- South	980	724	681
- West	984	679	658

Table 2: Reference office schedules during working days: occupancy [SIA, 2015], electrical appliances [SIA, 2015] and artificial lighting.

Time [h]	Human occupancy [-]	Appliances [-]	Artificial lighting [-]
1	0.0	0.1	0.0
2	0.0	0.1	0.0
3	0.0	0.1	0.0
4	0.0	0.1	0.0
5	0.0	0.1	0.0
6	0.0	0.1	0.0
7	0.0	0.1	0.0
8	0.2	0.2	1.0
9	0.6	0.6	1.0
10	1.0	0.8	1.0
11	1.0	1.0	1.0
12	0.8	0.8	1.0
13	0.4	0.4	1.0
14	0.6	0.6	1.0
15	1.0	1.0	1.0
16	0.8	0.8	1.0
17	0.6	0.6	1.0
18	0.2	0.2	1.0
19	0.0	0.1	0.0
20	0.0	0.1	0.0
21	0.0	0.1	0.0
22	0.0	0.1	0.0
23	0.0	0.1	0.0
24	0.0	0.1	0.0

Table 3: Boundary conditions of the numerical model of the reference office zone.

Geometry		
Floor area	27	m^2
Volume	81	m^3
WWR (gross)	60	%
Occupancy		
Full occupancy	3	pers
Crowding index	11	pers/m^2
Contemporaneity factor [SIA, 2015]	0.8	
Metabolic rate (office work) [SIA, 2015]	1.2	met
Façade building assembly – Glazing		
g-glass		
- Rome	0.33	-
- Stuttgart	0.59	-
- Stockholm	0.63	-
U-value (glass)		
- Rome	1.29	W/(m^{2}K)
- Stuttgart	1.40	W/(m^{2}K)
- Stockholm	0.81	W/(m^{2}K)
U-value (frame)	1.18	W/(m^{2}K)
Frame thickness	0.11	m
Facade building assembly – Lower infill element		
U-value (glass)		
- Rome	0.80	W/(m^{2}K)
- Stuttgart	0.40	W/(m^{2}K)
- Stockholm	0.30	W/(m^{2}K)
External solar shading		
Shading factor	70	%
Beam radiation for activation	120	W/m^2
Internal gains		
Persons [SIA, 2015]		
- Latent	0.08	kg/h/pers
- Sensible	70	W/pers
Appliances [SIA, 2015]	7.0	W/m^2
Artificial lighting	10.9	W/m^2
Ventilation		
Fresh-air supply	40	m^3/h/pers
Specific fan power	0.55	Wh/m^3
Heat recovery unit (HRU)	yes	-
Efficiency of the HRU [SIA, 2015]	70	%
By-pass	yes	-
Frost protection temperature	0	°C
Infiltration		
Air change rate	0.15	1/h
Thermal comfort		
Air temperature setpoint		
- Heating	20	°C
- Cooling	26	°C
- Hysteresis	1.0	K
Air humidity		
- Maximum	13.5	g_v/kg_a
- Minimum	4.5	g_v/kg_a
Max. heating power	unlimited	
Max. cooling power	unlimited	

Table 4: Construction assembly of internal walls.

Material	s [m]	λ [W/(mK)]	ρ [kg/m³]	c_p [kJ/(kgK)]
Plasterboard	0.024	0.160	950	0.84
Mineral wool	0.080	0.038	80	0.84
Plasterboard	0.024	0.160	950	0.84

Table 5: Construction assembly of floor/ceiling.

Material	s [m]	λ [W/(mK)]	ρ [kg/m³]	c_p [kJ/(kgK)]
Carpet	0.005	0.060	200	1.30
Screed	0.120	0.080	350	0.40
Concrete	0.350	2.100	2500	0.84

Table 6: Construction assembly of external wall.

Material	s [m]	λ [W/(mK)]	ρ [kg/m³]	c_p [kJ/(kgK)]
Aluminium	0.003	200	2700	0.86
Mineral wool	var.	0.038	80	0.84
Aluminium	0.003	200	2700	0.86

Table 7: Optical characteristics of indoor surfaces (valid for the overall solar spectrum).

Material	Reflectance [-]	Absorptance [-]	Emissivity [-]
Plasterboard	0.707	0.293	0.900
Mineral wool	0.384	0.616	0.900
Plasterboard	0.850	0.150	0.900

7. Appendix II: Monthly energy balance of the reference office zone (TRNSYS)

Table 8: Monthly energy balance for the reference office zone in Stockholm.

Month	Q_{HEAT}	Q_{COOL}	Q_{INF}	Q_{VENT}	Q_{TRANS}	Q_{GINT}	Q_{SOL}
	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)
January	5.37	0.00	-2.52	-1.99	-7.81	4.97	1.98
February	4.14	0.00	-2.34	-1.90	-7.33	4.33	3.10
March	2.01	0.00	-2.32	-2.47	-7.33	4.77	5.36
April	0.14	-0.16	-1.77	-3.57	-5.53	4.56	6.34
May	0.00	-1.85	-1.40	-3.83	-5.09	4.97	7.24
June	0.00	-5.18	-1.01	-2.43	-3.22	4.56	7.28
July	0.00	-7.62	-0.69	-1.56	-2.26	4.77	7.36
August	0.00	-6.47	-0.80	-2.13	-2.51	4.97	6.94
September	0.00	-1.95	-1.26	-3.34	-3.55	4.36	5.73
October	0.53	-0.03	-1.66	-3.24	-4.39	4.97	3.80
November	3.09	0.00	-1.94	-1.85	-5.67	4.75	1.62
December	5.16	0.00	-2.31	-1.76	-6.95	4.57	1.29
Total	***20.43***	***-23.25***	***-20.02***	***-30.08***	***-61.64***	***56.52***	***58.04***

Table 9: Monthly energy balance for the reference office zone in Stuttgart.

Month	Q_{HEAT}	Q_{COOL}	Q_{INF}	Q_{VENT}	Q_{TRANS}	Q_{GINT}	Q_{SOL}
	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)
January	5.11	0.00	-2.32	-2.11	-8.73	4.97	3.07
February	3.27	0.00	-1.95	-1.98	-7.47	4.33	3.81
March	1.85	0.00	-1.85	-2.55	-7.02	4.77	4.81
April	0.06	-0.33	-1.45	-3.20	-5.44	4.56	5.81
May	0.02	-2.89	-1.12	-3.09	-5.14	4.97	7.31
June	0.00	-5.44	-0.78	-1.74	-3.29	4.56	6.69
July	0.00	-5.84	-0.68	-1.63	-2.87	4.77	6.25
August	0.00	-5.78	-0.70	-1.81	-2.96	4.97	6.28
September	0.00	-2.13	-1.11	-2.78	-3.91	4.36	5.56
October	0.18	-0.15	-1.43	-3.40	-4.93	4.97	4.74
November	2.40	0.00	-1.79	-2.15	-6.25	4.75	3.03
December	5.12	0.00	-2.22	-1.87	-8.20	4.57	2.60
Total	***18.01***	***-22.56***	***-17.40***	***-28.32***	***-66.20***	***56.52***	***59.95***

Table 10: Monthly energy balance for the reference office zone in Rome.

Month	Q_{HEAT}	Q_{COOL}	Q_{INF}	Q_{VENT}	Q_{TRANS}	Q_{GINT}	Q_{SOL}
	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)	kWh/(m²y)
January	1.44	0.00	-1.59	-2.67	-4.67	4.97	2.53
February	0.95	0.00	-1.39	-2.41	-3.97	4.33	2.49
March	0.27	-0.04	-1.31	-2.83	-3.88	4.77	3.04
April	0.00	-0.57	-1.10	-2.51	-3.20	4.56	2.82
May	0.00	-3.38	-0.69	-1.57	-2.24	4.97	2.92
June	0.00	-5.51	-0.33	-0.56	-1.00	4.56	2.84
July	0.00	-7.02	-0.08	0.01	-0.19	4.77	2.51
August	0.00	-7.64	-0.04	0.04	-0.01	4.97	2.68
September	0.00	-4.74	-0.48	-0.88	-1.16	4.36	2.90
October	0.00	-3.08	-0.80	-2.06	-2.05	4.97	3.02
November	0.02	-0.46	-1.16	-2.94	-2.88	4.75	2.64
December	0.72	0.00	-1.44	-2.47	-3.90	4.57	2.52
Total	**3.40**	**-32.44**	**-10.39**	**-20.85**	**-29.15**	**56.52**	**32.91**