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USE OF ENERGY MODELLING SOFTWARE (IES VE) FOR HVAC SIZING, A COMPARISON WITH OLD PRACTICES

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ABSTRACT

This thesis presents a comparison and corresponding explanation of two different methods used in the HVAC pre-sizing and sizing tasks. The Effective Temperature Difference method (ETD) which presents a stationary approach, calculating the heating and cooling peak power for the hardest possible summer and winter conditions, using the common heat transfer equations and values stated in the Manualle della Climatizzazione an italian book for HVAC designing, and the Dynamic Energy Modelling methodology, which uses a software called IES-VE as a tool to calculate the total cooling and heating power required hourly by the thermal plant of a building. Both methods were applied on real study cases of Italian buildings which renovation and following HVAC design were led by Lombardini 22 Spa an italian architectural and engineering firm.

First each methodology is explained to later focus on the comparison of results and the possible differences obtained when performing both methods. Finally, some advantages of using the energy modelling option are commented. It is intended to be a starting point to help in the transition of more innovative practices that could lead in the design an correspond installation of more suitable HVAC systems for buildings in Italy, that can help in the future reduction of the energy consumption of the country and the world.

ABSTRACT (ITALIAN)

Questa tesi presenta un confronto e la corrispondente spiegazione di due diversi metodi utilizzati nei compiti di pre-dimensionamento e dimensionamento degli impianti di condizionamento. Il metodo Differenza di Temperatura Equivalente (ETD in inglese) che presenta un approccio stazionario, calcolando la potenza di picco di riscaldamento e raffreddamento per le condizioni estive e invernali più difficili possibili per l’edificio di analisi, utilizzando le comuni equazioni di trasferimento del calore e i valori indicati nel Manualle della Climatizzazione, libro italiano per la progettazione degli impianti, e la metodologia di Modellazione Dinamica dell'Energia degli edifici , che utilizza un software chiamato IES-VE come strumento per calcolare la potenza totale di raffreddamento e riscaldamento richiesta ogni ora dall’impianto. Entrambi i metodi sono stati applicati a casi studio reali di edifici italiani la cui ristrutturazione e successiva progettazione dell’impianto è stata condotta da Lombardini 22 Spa, uno studio di architettura e ingegneria italiano.

Prima viene spiegata ogni metodologia per poi concentrarsi sul confronto dei risultati e sulle possibili differenze ottenute nell'esecuzione di entrambi i metodi. Infine, vengono commentati alcuni vantaggi dell'utilizzo dell'opzione corrispondente alla modellazione energetica. Si vuole essere un punto di partenza per aiutare nella transizione di pratiche più innovative che potrebbero portare alla progettazione e all'installazione di impianti più adatti agli edifici in Italia, che possono aiutare nella futura riduzione del consumo energetico del paese e del mondo.

To Gaia, the magical and unique world/living system, which we all conform.
To my parents and friends that join me in this beautiful journey called life.

USE OF ENERGY MODELLING SOFTWARE (IES VE) FOR HVAC SIZING, A COMPARISON WITH OLD PRACTICES

INDEX

1. The Italian version of the Carrier method

1.1. The estimation of the energy and the peak-power needs of a building

Carrier method[1] models the interaction between indoor environment and the outdoor space, in terms of thermal energy losses and gains through the building envelope. This to estimate the peak-power needs, i.e. the maximum power that the HVAC system must be able to provide to or/- extract from the building, in order to ensure the indoor comfort design conditions, in terms of air temperature and relative humidity in each thermal zone.

The peak-power is evaluated, in the summer and winter season, estimating:

- The thermal exchanges between each thermal zone and the outdoor environment (mainly represented by its air temperature) through its envelope, roof included, represented by the thermal transmittance of every different component.
- The thermal exchanges between each thermal zone and other conditioned or non-heated spaces (at different temperature conditions), through each different partition component, again represented by their thermal transmittance.
- The thermal exchanges toward the ground, if any.
- The solar radiation entering each thermal zone, through transparent surfaces, characterized by their solar transmittance and their effect on modifying the conduction exchange on opaque surfaces changing their humidity conditions.
- The internal loads (only in summer condition) produced by people, lighting, and equipment inside each thermal zone.

The evaluation of the power demand is carried out by calculating, under steady state worst design conditions (external lowest air temperature in winter and highest air temperature in summer), the thermal power needed in each thermal zone of the building, to maintain acceptable comfort conditions inside of them (usually an air temperature between 20 and 26ºC).

Each thermal zone's energy need is summed up to obtain the total energy exchange of the entire building with the outside space, for both summer and winter scenario. This cooling and heating peak power must be able to be provided by the HVAC system to ensure the balance between the incoming and outgoing total thermal flux, during the most demanding days of the year.

$$\sum_{i=1}^{N^{\underline{o}}\,T.zones} (\dot{Q}_{in,i} - \dot{Q}_{out,i}) = \dot{Q}_{peak}$$

All these calculations are based on the hypothesis that the daily variation may be neglected, which is acceptable for the heating period, but not in the cooling one, when a single thermal zone may change its thermal balance from positive (needing cooling) to negative (needing heating) in the same day. Furthermore, due to the sun movement, some thermal zones will peak in cooling needs during the early morning while others at midday or during the late afternoon, so that the global need cannot be just the sum of the single peaks, because they can be at different hours, but must be the higher value between the sum calculated at different hours of the day, usually at 9h,12h and 16h.

$$\dot{Q}_{peak,summer} = MAX(\dot{Q}_{9h}; \dot{Q}_{12h}; \dot{Q}_{16h})$$

1.2. Conductive thermal exchanges between internal conditioned spaces and the external air

The law of heat conduction, also known as Fourier's law, states that the rate of heat transfer through a material is proportional to the gradient in the temperature and to the area, at right angles to that gradient, through which the heat flows.

Therefore, through the building envelope this kind of heat transfer takes place promoted by the difference of temperature between inside and outside spaces, where the heat is transferred from the hotter to the colder space through the envelope following the definition of thermal transmittance and the mentioned Fourier's law:

$$\dot{Q} = U * A * \Delta T$$

With:

- $\dot{Q}$ is the amount of heat transferred per unit of time, in W.
- U is the material's conductance, in W/(m^2·K).
- A is the cross-sectional surface area, perpendicular to the heat transfer direction, in m^2.
- ΔT is the temperature difference between the surfaces, in K. The difference between internal and external air on this context.

Thermal energy transmission through the vertical envelope, especially during summer condition, is not only determined by the difference between the exterior and interior air temperature but also by the action of the solar radiation on the exterior surfaces, which determines the temperature of the most external wall/window layer and humidity condition of it, modifying the overall thermal flux by conduction.

1.2.1. Solar radiation impact on winter scenario

Less irradiated surfaces as walls facing north at the north hemisphere, present remarkable higher humidity levels during winter season, increasing the conduction transfer through them. On the contrary, south facing façades are usually dry since the irradiance of the sun evaporates the moist or rain particles. Therefore, on winter condition, the final $\dot{Q}$ value is multiplied by a factor F_o intended for "*Fattore correttivo dovuto all'orientamento"* which increases the conduction according to the specific wall's exposition. (Taken from *UNI 7357, par.9*.)

$$\dot{Q}_f = \dot{Q} * F_o = U * A * \Delta T * F_o$$

With $\dot{Q}_f$ as the final amount of heat transferred per unit of time during winter condition, considering the effect of the solar radiation, in W.

1.2.2. Solar radiation impact on summer scenario

ΔT on opaque closures, depends greatly on the solar radiation since the external layer of the façade is heated up by the sun, modifying completely the conduction transfer through it.

To calculate the final conduction value, is applied the Total Equivalent Temperature Differential method (TETD), where the concept of ΔT_{eq} is introduced. It states the corresponding heat transfer between the exterior and interior spaces, while considering the effect of the solar radiation. The new ΔT depends on the mass (due to the thermal capacity) of the wall or roof, their exposition, site's latitude, the hour of the day and the stated project conditions.

As the solar radiation and external air temperature are not fixed together along the year, it's impossible to talk about a permanent or stationary regime of the thermal transmission, making it harder to state a precise ΔT value. Therefore, some values of ΔT_{eq} were measured under certain specific conditions of colour, external and internal air temperature, daily variation of the temperature and latitude for a specific month and time of analysis, they are called ΔT_{em}, and are stated on the *Chapter 1.7* from *Manuale della Climatizzazione Tab.3.17* – "*Differenza di temperature equivalente*".

ΔT_{em} values were calculated for a dark roof or wall, external temperature of 35ºC, internal temperature of 27ºC, daily ΔT of 11ºC for the month of July on a 40º North Latitude. For different conditions, coefficients α and b are implemented to correct the measured ΔT_{em} value above, finding a corresponding ΔT_{eq} for the new conditions. The calculation follows the next equation:

$$\Delta T_{eq} = a + \Delta T_{es} + b * \frac{R_s}{R_m} * (\Delta T_{em} - \Delta T_{es})$$

Where:

- ΔT_{eq} as a corrected ΔT to be used in the conduction heat transfer formula, for summer condition.
- α intended as a Correction Value when the Exterior minus interior temperature difference has a value other than 8 ºC, in ºC - (*See Chapter 1.7*)
- ΔT_{es} as Equivalent temperature difference under shady condition, in ºC (*See Chapter 1.7*)
- b as colour factor, depends on the colour of the wall or roof (1 for dark, 0.78 for medium and 0.55 for light colour), unitless.
- R_m as the maximum solar radiation from all the orientations in July at 40º Latitude, in W/m^2 - (*See Chapter 1.7*)
- R_S as the maximum solar radiation specific for the wall orientation at building's latitude during the month of analysis, in W/m^2. (*See Chapter 1.7*)
- ΔT_{em} as measured ΔT_{eq} values under the certain specific conditions mentioned above, in ºC. (*See Chapter 1.7*)

1.3. Conductive thermal exchanges between internal spaces at different temperature conditions

As for the exterior building envelope, different temperature conditions between interior spaces generate transfer of heat by conduction through the internal divisions inside the building, either slabs or internal walling. These different thermal conditions could be either because different temperature setpoints are stated on the spaces, or because some internal areas are not subjected to conditioning, leaving them with a free flux of temperature.

For the calculation of transfer of heat on conditioned spaces facing these kind of areas, the conduction formula is applied, while the ΔT is multiplied by a factor $b_{tr,u}$ called “Fattore di correzione” taken from UNI EN 12831:200, which its value depends on the classification of the adjacent space, following the table below.

prospetto 7 **Fattore di correzione $b_{tr,U}$ (da UNI EN 12831:2006)**

Ambiente confinante	$b_{tr,U}$
Ambiente - con una parete esterna - senza serramenti esterni e con almeno due pareti esterne - con serramenti esterni e con almeno due pareti esterne (per esempio autorimesse) - con tre pareti esterne (per esempio vani scala esterni)	 0,4 0,5 0,6 0,8
Piano interrato o seminterrato - senza finestre o serramenti esterni - con finestre o serramenti esterni	 0,5 0,8
Sottotetto - tasso di ventilazione del sottotetto elevato (per esempio tetti ricoperti con tegole o altri materiali di copertura discontinua) senza rivestimento con feltro o assito - altro tetto non isolato - tetto isolato	 1,0 0,9 0,7
Aree interne di circolazione (senza muri esterni e con tasso di ricambio d'aria minore di 0,5 h^{-1})	0,0
Aree interne di circolazione liberamente ventilate (rapporto tra l'area delle aperture e volume dell'ambiente maggiore di 0,005 m^2/m^3)	1,0
Solette sospese (solette sopra vespaio)	0,8
Pavimento o parete controterra	0,45

$$\dot{Q} = U * A * \Delta T * b_{tr,u}$$

1.4. Radiation thermal exchanges through transparent surfaces

The total thermal flux entering through transparent glass surfaces is determined by two different contributions:

$$\dot{Q} = \dot{Q}_c + \dot{Q}_r$$

Where:

$\dot{Q}_c$ = is thermal flux due to the temperature difference between two ambients (internal and external air), in W.

$\dot{Q}_r$ = is thermal flux due to the incident radiation entering the space, in W .

The first term is calculated by the standard conduction equation, as seen on the ***Chapter 1.2.***, while the second follows the next equation:

$$\dot{Q}_r = A * I_{max} * A_{cc} * C_f$$

With:

- A as the window area, perpendicular to the heat transfer, in m^2.
- I_{max} as the maximum irradiation on the window orientation for the project's latitude, at the month of the analysis, in W/m^2. (*See Chapter 1.7*)
- A_{cc} as accumulation Coefficient, which defines the amount of heat that remains inside the space over time, depends on the location of the screen/coating (internal or external) and the number of conditioned hours per day for the thermal space, unitless. (*See Chapter 1.7*)
- C_f as Correction Factor, which modifies the irradiance passing through the surface depending on the window and frame typology, screen/coating or blind presence and climate conditions of the site, unitless. It follows the equation below:

$$C_f = F_{shad+screen} * F_{fog} * F_{frame} * F_{dew-point} * F_{altitude}$$

Where:

- $F_{shading+screen}$ as Shading+Screen Factor, varies according on the number of glass layers, their thickness and colour, and the absorption coefficient of the external one. Goes from 1 to 0.1. (*See Chapter 1.7*)
- F_{fog} Reduces the irradiance due to the presence of fog, goes from 1 for no fog to 0.75 for heavy fog on the site.
- F_{frame} = 1.17 for metal frame or no frame, and 1 for other frame material.
- $F_{dew-point}$ modifies the irradiance when the dew point temperature $T_{dew\text{-}point}$ of the project is different to 19.5 °C. Follows the equation: $1-(T_{dew\text{-}point} - 19.5°C)/10*0.13$. Can be greater or less than 1.
- $F_{altitude}$ increases the irradiance by 0.7% for each 300 m of altitude, its equal to: 1 + Project altitude/300 * 0.007.

1.5. Internal Loads produced inside the thermal spaces

Further from the energy transmission through the building envelope by conduction and radiation, entering or leaving the internal space, the internal gains produced inside are also of great importance, especially during summer condition since they increase the amount of heat power that need to be extracted from each thermal space by the HVAC system, modifying in this way the Cooling Peak Power of the building. Their value depends on the typology of use of each thermal space, and they are mostly produced by People, lighting, and Equipment, stated on the tables below.

- For people – *tab 3.30 Carichi termici dovuti alle persone* - *Manuale della Climatizzazione.*

Tab. 3.30 - Carichi termici dovuti alle persone (W).

Grado di attività	Tipo di applicazione	Metabolismo uomo adulto	Metabolismo medio*	Temperatura a bulbo secco del locale (°C)									
				28		27		26		25		24	
				(W)		(W)		(W)		(W)		(W)	
		(W)	(W)	Sensibile	Latente	Sensibile	Latente	Sensibile	Latente	Sensibile	Latente	Sensibile	Latente
Seduto e in riposo	Teatro o scuole infer.	114	102	51	51	57	45	61	41	67	35	76	26
Seduto, lavoro leggero	Scuola	132	117	53	64	57	60	63	54	70	47	80	37
Impiegato d'ufficio	Uffici-alberghi Appartamenti-college	139	132	53	79	59	73	63	69	71	61	84	48
In piedi, leggero movimento	Empori-boutique, vendita al dettaglio	161											
Seduto o in leggero movim.	Farmacia	161	147	53	94	59	88	65	82	75	62	85	62
In piedi, leggero movimento	Banca	161											
Lavoro sedentario	Ristorante**	147	161	56	105	64	97	70	91	82	79	94	67
Lavoro leggero al banco	Officina assemblag.	234	220	56	164	64	156	72	148	87	133	107	113
Ballo moderato	Sala da ballo	264	249	64	185	72	177	81	168	95	154	117	132
In movimento 1,4 m/s	Officina, lavoro pes.	293	293	79	214	88	295	97	196	111	182	135	158
Lavoro pesante	Bowling***-fabbrica	440	425	132	293	136	289	142	283	154	271	177	248

*Il "metabolismo medio" è quello che corrisponde a un gruppo formato da adulti e bambini dei due sessi, nelle normali condizioni. Questi valori sono stati ottenuti partendo dalle seguenti ipotesi:

metabolismo della donna = metabolismo dell'uomo × 0,85;
metabolismo del bambino = metabolismo dell'uomo × 0,75.

** Questi valori comprendono una maggiorazione di 18 W (50% di calore sensibile e 50% di latente) per persona per tener conto del calore emesso dalle vivande.

*** Si suppone che stia giocando a bowling una sola persona per pista e le altre siano sedute (114 W) o in piedi (161 W).

- For lighting – *tab 3.33- Dati approssimati per I carichi di illuminazione qj per diversi edifici - Manuale della Climatizzazione.*

Tab. 3.33 - Dati approssimati per i carichi di illuminazione q_i per diversi edifici.

Edificio	q_i					
	Basso		Medio		Alto	
	(W/m²)	(kcal/hm²)	(W/m²)	(kcal/hm²)	(W/m²)	(kcal/hm²)
Appartamenti	10	9	20	17	45	39
Abitazioni	10	9	20	17	45	39
Auditorium, chiese, teatri	10	9	20	17	30	26
Scuole, collegi, università	20	17	45	39	65	56
Officine montaggio	30	26	50	43	65	56
Lavorazioni leggere	100	86	110	95	130	112
Lavorazioni pesanti	160	138	500	430	650	559
Ospedali						
– degenze	10	9	15	13	20	17
– aree aperte al pubblico	10	9	15	13	20	17
Hotel, motel, dormitori	10	9	20	17	30	26
Librerie, musei	10	9	15	13	30	26
Edifici per uffici (valori totali)	45	39	65	56	100	86
Ristoranti	15	13	20	17	25	21
Barbieri, istituti di bellezza	35	30	50	43	100	86
Grandi magazzini						
– piano terra	20	17	35	30	45	39
– piano principale	40	34	65	56	100	86
– piani superiori	20	17	30	26	40	34
Abbigliamento	10	9	20	17	45	39
Farmacia	10	9	20	17	35	30
Cappelli	10	9	20	17	35	30
Scarpe	10	9	20	17	35	30
Gallerie	10	9	15	13	20	17

Fonte: ASHRAE, *Pocket guide for air conditioning, heating, ventilation, refrigeration*, ASHRAE, Atlanta, GA, 1997.

- For Equipment gains– *tab 3.34- Valori indicative del flusso sensibile qs e della portata di vapore G, dovuti alla presenza di apparecchiature.*

Tab. 3.34 - Valori indicativi del flusso termico sensibile q_s e della portata di vapore G_v, dovuti alla presenza di apparecchiature caratterizzate dalla potenza massima assorbita P.

Apparecchiatura	P_{max}		q_s		G_v
	(W)	(kca/h)	(W)	(kca/h)	(g/h)
APPARECCHIATURE PER UFFICIO					
– personal computer	100÷600	86÷516	90÷550	77÷473	
– minicalcolatori	2000÷6500	1720÷5589	2000÷6500	1720÷5589	
– stampanti laser	850	731	350	301	
– copiatrici eliografiche	1100÷2500	945÷2150	1100÷2500	945÷2150	
– fotocopiatrici	450÷6600	386÷5675	450÷6600	386÷5675	
– scanner	1700	1462	1500	1290	
– imbustatrici ed etichettatrici	600÷6000	515÷5159	400÷4000	344÷3440	
– distributori di acqua refrigerata	700	602	1750	1505	
– distributori di bevande fredde	1200÷1900	1031÷1634	550÷900	473÷774	
– macchine per il caffè	1500	1290	1000	860	650
– forni a microonde	600	516	400	344	
– distruttori di documenti	250÷3000	214÷2579	200÷2400	172÷2064	
APPARECCHIATURE OSPEDALIERE					
– piccola autoclave	1250	1078	140	120	
– bagni	750÷1800	645÷1548	100÷300	86÷258	350÷850
– analizzatore di sangue	1000	862	1000	860	
– grande centrifuga	1100	948	1100	946	
– cromatografo	2000	1724	2000	1720	
– citometro	21.000	18.103	21.000	18.057	
– incubatrice a ventilazione forzata	720	621	360	310	
– agitatore magnetico	600	517	600	516	
– fornetto da laboratorio	1300	1121	200	172	
– frigorifero da laboratorio	100	86	50	43	
– spettrofotometro	500	431	500	430	
– sterilizzatrice	21.000	18.103	2500	2150	
– lavatrice per vetreria	4500	3879	3000	2580	
APPARECCHIATURE PER RISTORANTE					
Apparecchiature elettriche senza cappa					
– caffettiera (per l)	650	560	450	387	300
– lavastoviglie (per 100 piatti/h)	400	345	50	43	150
– riscaldatore infrarosso (per lampada)	250	216	250	215	0

(Segue)

Tab. 3.34 - *(Continua dalla pagina precedente).*

Apparecchiatura	P_{max} (W)	(kca/h)	q_s (W)	(kca/h)	G_v (g/h)
– riscaldatore a immersione (per l)	50	43	20	17	10
– griglia (per m^2)	29.000	25.000	2000	1720	1600
– piatto riscaldatore	4900	4224	2300	1978	2300
– cubettatrice da ghiaccio	1100	948	2750	2365	
– mixer (per l)	50	43	50	43	
– frigorifero (per 1000 l)	100	86	50	43	
– congelatore	1350	1164	550	473	
– carrello servizio cibi caldi (per l)	50	43	10	9	5
– tostatrice	5300	4569	2800	2408	3500
Apparecchiature elettriche con cappa					
– griglia (per m^2)	23.000	19.828	1000	860	
– friggitrice (per kg di olio)	800	690	10	9	
– friggitrice pressurizzata (per kg di olio)	1000	862	50	43	
– forno (per 1000 l)	46.000	39.655	2000	1720	
Apparecchiature a gas, senza cappa					
– griglia (per m^2)	50.000	43.103	17.000	14.617	13.000
– lavastoviglie (per 100 piatti/h)	400	345	100	86	50
– forno per pizza (per m^2)	15.000	12.931	2000	1720	1000
Apparecchiature a gas, con cappa					
– pentolone (per l)	3000	2586	750	645	
– griglia (per m^2)	50.000	43.103	2500	2150	
– friggitrice (per kg di olio)	1500	1293	0	0	100
– forno (per l)	100	86	10	9	
– forno per pizza (per m^2)	20.000	17.241	500	430	
– fornello (per 2 becchi)	10.000	8621	2000	1720	
– fornello a piano (per m^2)	35.000	30.172	10.000	8598	
Apparecchiature a vapore, senza cappa					
– riscaldatore (per kg/h di cibo)	200	172	20	17	15
– lavastoviglie (per 100 piatti/h)	900	776	200	172	150
– lavastoviglie (per 100 piatti/h)	350	302	50	43	150
Apparecchiature a vapore, con cappa					
– riscaldatore (per kg/h di cibo)	200	172	10	9	
– lavastoviglie (per 100 piatti/h)	900	776	100	86	
– lavastoviglie (per 100 piatti/h)	350	302	50	43	
NEGOZI E SUPERMERCATI					
Banchi frigoriferi aperti					
– surgelati, a 1 piano (per m di banco)			200	172	–50
– surgelati, a 2 piani (per m di banco)			550	473	–200
– surgelati, a 3 piani (per m di banco)			1250	1075	–450
– surgelati, a 4 o 5 piani (per m di banco)			1550	1333	–550
– gelati (per m di banco)			350	301	–100
– carni, a 1 piano (per m di banco)			300	258	–100
– carni, a più piani (per m di banco)			850	731	–300
– latticini, a più piani (per m di banco)			750	645	–250
– altri prodotti, a 1 piano			200	172	–50
– altri prodotti, a più piani			750	645	–250

Fonte: ASHRAE, *Pocket guide for air conditioning, heating, ventilation, refrigeration*, ASHRAE, Atlanta, GA, 1997.

1.6. Parameters applied on the method

During the calculation process mentioned above, it is necessary the use of several thermal, climatic, material and irradiation parameters to be inserted into the specific equations in order to calculate each of the energy transfers. They were taken mostly from the "Manuale della Climatizzazione" as a main source of knowledge and are explained on this chapter below.

1.1.1. Thermal and climatic parameters of the zone.

- Design temperatures for ΔT calculation:

  Exterior winter design temperature and interior winter design temperature are taken from *DPR. N.412 del 26.8.1993-DM 10.3.1997* summarized in *Manuale della Climatizzazione - tab.3.10 "Temperatura dell'aria esterna di Progetto e gradi giorno (riscaldamento invernale)"* and *3.5.2 Condizioni di progetto,* also from *Manuale della Climatizzazione.*

Tab. 3.10 - Temperatura dell'aria esterna di progetto e gradi giorno (riscaldamento invernale) DPR n. 412 del 26.8.1993, DPR n. 1052 del 28.6.1977, DM 10.3.1977 e DM 16.5.1995.

Comune	Quota s.l.m. (m)	Temperatura aria esterna di progetto (°C)	Zona climatica	Gradi giorno
Agrigento	230	3	B	729
Alassio	6		C	1206
Alessandria	95	–8	E	2559
Amatrice	955		F	3048
Ancona	16	–2	D	1688
Aosta	583	–10	E	2850
Arezzo	296	0	E	2014
Ariano Irpino	778		E	2410
Ascoli Piceno	154	–2	D	1698
Asti	123	–8	E	2617
Atri	442		D	2068
Auronzo	864		F	4166
Avellino	348	–2	D	1742
Bari	5	0	C	1185
Belluno	383	–10	E	2936
Benevento	135	–2	C	1316
Bergamo	249	–5	E	2533
Bertinoro	220		E	2435
Biella	420		E	2589
Bologna	55	–5	E	2259
Bolzano	262	–15	E	2791
Bormio	1225		F	3838
Brescia	149	–7	E	2410
Bressanone	559		F	3507
Brindisi	15	0	C	1083
Cagliari	4	3	C	990
Caltanissetta	568	0	D	1550
Camerino	661		E	2481
Campobasso	701	–4	E	2346
Caserta	68	0	C	1013
Catania	7	5	B	833
Catanzaro	320	–2	C	1328
Chieti	330	0	D	1556
Como	201	–5	E	2228
Corleone	542		D	1481
Cosenza	237	–3	C	1317
Courmayeur	1224		F	3926
Cuneo	534	–10	F	3012
Cremona	45	–5	E	2389
Crotone	8		B	899
Desenzano	66		E	2229
Desulo	886		E	2169
Dobbiaco	1256		F	4503
Edolo	699		F	3209
Enna	931	–3	E	2248
Fabriano	325		E	2198
Ferrara	9	–5	E	2326
Firenze	50	0	D	1821
Floresta	1275		F	3309
Foggia	76	0	D	1530
Foligno	234		D	1899
Foppolo	1508		F	4444
Forlì	34	–5	D	2087
Frosinone	291	0	E	2196
Gallipoli	12		C	999
Genova	19	0	D	1435
Gorizia	84	–5	E	2333
Grosseto	10	0	D	1550
Iesi	97		D	1899
Imperia	10	0	C	1201
Isola del Cantone	298		E	2199
Ivrea	253		E	2737
Lacedonia	732		E	2377
L'Aquila	714	–5	E	2514
La Spezia	3	0	D	1413
Latina	21	2	C	1220
Lecce	49	0	C	1153
Livorno	3	0	D	1408
Lucca	19	0	D	1715
Lucera	219		D	1473
Macerata	315	–2	D	2005
Macomer	563		D	1580
Mantova	19	–5	E	2388
Massa Carrara	65	0	D	1525
Matera	200	–2	D	1418
Melfi	530		D	1841
Messina	3	5	B	707
Milano	122	–5	E	2404
Milazzo	1		B	28
Mineo	511		C	1293
Modena	34	–5	E	2258
Mores	366		D	1611
Napoli	17	2	C	1034
Norcia	604		E	2608
Novara	159	–5	E	2463
Nuoro	546	0	B	1602
Ortisei	1.234		F	4407
Padova	12	–5	E	2383
Palermo	14	5	B	751
Parma	57	–5	E	2502
Pavia	77	–5	E	2623
Pavullo nel Frignano	682		F	3348
Perugia	493	–2	E	2289
Pesaro	11	–2	D	2083
Pescara	4	2	B	1718
Pescopagano	954		E	2712
Piacenza	61	–5	E	2715
Pienza	491		E	2113
Pisa	4	0	D	1694
Pordenone	24	–5	E	2459
Porretta Terme	349		E	2648
Potenza	819	–3	E	2472
Ragusa	502	0	C	1324
Ravenna	4	–5	E	2227
Recoaro	450		E	2879
Reggio Calabria	15	3	B	772
Reggio Emilia	58	–5	E	2560
Rieti	405	–3	E	2324
Riposto	6		B	857
Roma	20	0	D	1415
Rovigo	7	–5	E	2466
Salerno	4	2	C	994
Salò	75		E	2265
Sassari	225	2	C	1185
Savona	4	0	D	1481
Sestola	1020		F	3419
Siena	322	–2	D	1943
Siracusa	17	5	B	799
Sondrio	307	–10	E	2755
Taranto	15	0	C	1071
Tarvisio	732	–15	F	3959
Teramo	265	0	D	1834
Terni	130	–2	D	1650
Torino	239	–8	E	2617
Trapani	3	5	B	810
Trento	194	–12	E	2567
Treviso	15	–5	E	2378
Trieste	2	–5	D	1929
Tropea	61		C	912
Udine	113	–5	E	2323
Urbino	485		E	2545
Varese	382	–5	E	2652
Venezia	1	–5	E	2345
Vercelli	130	–7	E	2751
Verghereto	812		F	3153
Verona	59	–5	D	2068
Vicenza	39	–5	E	2371
Viterbo	326	–2	D	1989

(Segue)

Exterior summer design temperature is taken from UNI 10339 *Impianti aeraulici a fini di benessere* summarized in *Manuale della Climatizzazione - tab. 3.5."Condizioni esterne estive di progetto per diverse località italiane.*

Tab. 3.5 - Condizioni esterne estive di progetto per diverse località italiane.

Località	Temperatura di progetto a bulbo secco (°C)	Temperatura di progetto a bulbo umido (°C)	Escursione media giornaliera (°C)	Umidità relativa (%)	Umidità specifica (g/kg)
Ancona	29,5	23,8	5,5	63	16,2
Aosta	29,0	21,2	13,0	50	12,6
Bari	32,0	24,4	8,0	50	15,0
Bologna	33,0	22,4	12,0	43	13,6
Bolzano	31,5	22,2	13,0	45	13,0
Cagliari	32,0	23,9	9,0	52	15,4
Campobasso	29,0	21,2	9,0	50	12,6
Catanzaro	33,0	22,4	10,0	40	12,6
Firenze	33,5	21,2	13,0	45	14,6
Genova	30,0	24,4	6,0	60	16,0
L'Aquila	29,0	21,2	10,0	50	12,6
Milano	32,0	23,3	12,0	48	14,4
Napoli	32,0	23,8	10,5	45	13,3
Palermo	32,0	22,6	6,5	45	13,3
Perugia	30,5	20,6	10,0	40	11,0
Potenza	28,5	19,0	9,5	40	9,8
Roma	33,0	22,8	11,5	45	14,2
Torino	30,5	23,8	11,0	50	16,4
Trento	31,0	21,8	12,0	45	12,6
Trieste	31,0	26,0	8,0	50	14,1
Venezia	31,0	24,4	9,0	51	14,4

Note
(a) La temperatura a bulbo secco esterna può essere corretta per tener conto della diversa situazione dell'ambiente esterno (temperatura invariata per edifici isolati, aumento da 0,5 a 1 °C in piccoli agglomerati, aumento da 1 a 2 °C in un complesso urbano.
(b) In base alla temperatura corretta in conformità alla nota (a), l'umidità relativa viene modificata come segue: per l'Italia settentrionale, mantenendo la stessa umidità specifica; per l'Italia centrale, facendo la media tra l'umidità relativa corrispondente.

Fonte: UNI 10339, *Impianti aeraulici a fini di benessere. Regole per la richiesta d'offerta, l'offerta, l'ordine e la fornitura. Generalità, classificazione e requisiti.*

For other design temperatures such as non-conditioned spaces, the ΔT is multiplied by a factor $b_{tr,u}$ called Fattore di correzione taken from UNI EN 12831:2006

prospetto D.4 **Fattore di riduzione della temperatura, b_u**

Spazio non riscaldato	b_u
Ambiente	
con solo 1 parete esterna	0,4
con almeno 2 pareti esterne senza porte esterne	0,5
con almeno 2 pareti esterne con porte esterne (per esempio, atri, garage)	0,6
con 3 pareti esterne (per esempio, vano scala esterno)	0,8
Seminterrato	
senza finestre/porte esterne	0,5
con finestre/porte esterne	0,8
Sottotetto	
alto tasso di ventilazione del sottotetto (per esempio tetti con rivestimento di tegole o altri materiali che forniscono una copertura discontinua) senza feltri o tavole di sottostruttura	1,0
altro tipo di tetto non isolato	0,9
tetto isolato	0,7
Vani scala e disimpegni interni (senza pareti esterne, tasso di ventilazione minore di 0,5 h^{-1})	0
Vani scala e disimpegni con apertura verso l'esterno (area delle aperture/volume dello spazio >0,005 m^2/m^3)	1,0
Pavimento su intercapedine (pavimento sopra vespaio)	0,8

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1.1.2.Thermal conduction parameters.

- Thermal transmittance values “U” taken from *Manuale della Climatizzazione. - tab 3.4 “Resistenze termiche totali R delle diverse strutture impiegate nell’edilizia civile”* following the minimum energy requirements for Italy from “*Decreti sulle prestazioni energetiche e certificazione degli edifici” Appendice A.*

- F_o intended for “*Fattore correttivo dovuto all’orientamento”* which increases the conduction according to the external wall’s exposition taken from *UNI 7357, par.9*.

Esposizione	S	SO	O	NO	N	NE	E	SE
Coefficiente f	1	1,02-1,05	1,05-1,10	1,10-1,15	1,15-1,20	1,15-1,20	1,10-1,15	1,05-1,10

1.1.3.Irradiation parameters and modifications.

- The specific values of ΔT_{eq} measured under certain specific conditions called ΔT_{em} for a dark wall, external temperature of 35ºC, internal temperature of 27ºC, daily ΔT of 11ºC for a July month at 15h on a 40º North Latitude. From *Manuale della Climatizzazione. - tab 3.17 “Differenza di temperatura equivalente (ºC).*

Tab. 3.17 - Differenza di temperatura equivalente (°C). Muri irradiati o in ombra*. Valida per muri di colore scuro, temperatura esterna 35 °C, temperatura interna 27 °C, escursione della temperatura esterna nelle 24 ore pari a 11 °C, mese di luglio e 40° di latitudine nord.**

Orientamento	Massa frontale *** (kg/m^2)	Ora solare																							
		Mattino							Pomeriggio-Notte													Mattino				
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
NE	100	2,8	8,3	12,2	12,8	13,3	10,6	7,8	7,2	6,7	7,2	7,8	7,8	7,8	6,7	5,5	4,4	3,3	2,2	1,1	0,0	−1,1	−1,7	−2,2	−1,1
	300	−0,5	−1,1	−1,1	2,8	13,3	12,2	11,1	8,3	5,5	6,1	6,7	7,2	7,8	7,2	6,7	6,1	5,5	4,4	3,3	2,2	1,1	0,5	0,0	−0,5
	500	2,2	1,7	2,2	2,2	2,2	5,5	8,9	8,3	7,8	6,7	5,5	6,1	6,7	6,7	6,7	6,1	5,5	5,0	4,4	3,9	3,3	3,3	2,8	2,8
	700	2,8	2,8	3,3	3,3	3,3	3,3	3,3	5,5	7,8	8,9	7,8	6,7	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,0	5,0	4,4	3,9	3,9
E	100	0,5	9,4	16,7	18,3	20,0	19,4	17,8	11,1	6,7	7,2	7,8	7,8	7,8	6,7	5,5	4,4	3,3	2,2	1,1	0,0	−0,5	−1,1	−1,7	−1,7
	300	−0,5	−0,5	0,0	11,7	16,7	17,2	17,2	10,6	7,8	7,2	6,7	7,2	7,8	7,2	6,7	6,1	5,5	4,4	2,8	2,2	1,7	0,5	0,5	0,0
	500	2,8	2,8	3,3	4,4	7,8	11,1	13,3	13,9	13,3	11,1	10,0	8,9	7,8	7,8	7,8	7,2	6,7	6,1	5,5	5,0	4,4	3,9	3,9	3,3
	700	6,1	5,5	5,5	5,0	4,4	5,0	5,5	8,3	10,0	10,6	10,0	9,4	8,9	7,8	6,7	7,2	7,8	7,8	7,8	7,2	7,2	6,7	6,7	6,7
SE	100	5,5	3,3	7,2	10,6	14,4	15,0	15,6	14,4	13,3	10,6	8,9	8,3	7,8	6,7	5,5	4,4	3,3	2,2	1,1	0,0	−0,5	−0,5	−1,1	−1,1
	300	0,5	0,5	0,0	7,2	11,1	13,3	15,6	14,4	13,9	11,7	10,0	8,3	7,8	7,2	6,7	6,1	5,5	4,4	3,3	2,8	2,2	1,7	1,7	1,1
	500	3,9	3,9	3,3	3,3	3,3	6,1	8,9	9,4	10,0	10,6	10,0	9,4	7,8	7,2	6,7	6,1	5,5	5,5	5,5	5,0	5,0	4,4	4,4	3,9
	700	5,0	4,4	4,4	4,4	4,4	3,9	3,3	6,1	7,8	8,3	8,9	10,0	8,9	8,3	7,8	7,2	6,7	6,7	6,7	6,1	6,1	5,5	5,5	5,0
S	100	−0,5	−1,1	−2,2	0,5	2,2	7,8	12,2	15,0	16,7	15,6	14,4	11,1	8,9	6,7	5,5	3,9	3,3	1,7	1,1	0,5	0,5	0,0	0,0	−0,5
	300	−0,5	−1,7	−2,2	−1,7	−1,1	3,9	6,7	11,1	13,3	13,9	14,4	12,8	11,1	8,3	6,7	5,5	4,4	3,3	2,2	1,1	0,5	0,5	0,0	−0,5
	500	2,2	2,2	1,1	1,1	1,1	1,7	2,2	4,4	6,7	8,3	8,9	10,0	10,0	8,3	7,8	6,1	5,5	5,0	4,4	4,4	3,9	3,3	3,3	2,8
	700	3,9	3,3	3,3	2,8	2,2	2,2	2,2	2,2	2,2	3,9	5,5	7,2	7,8	8,3	8,9	8,9	7,8	6,7	5,5	5,5	5,0	5,0	4,4	3,9
SO	100	−1,1	−2,2	−2,2	−1,1	0,0	2,2	3,3	10,6	14,4	18,9	22,2	22,8	23,3	16,7	13,3	6,7	3,3	2,2	1,1	0,5	0,5	0,0	−0,5	−0,5
	300	1,1	0,5	0,0	0,0	0,0	0,5	1,1	4,4	6,7	13,3	17,8	19,4	20,0	19,4	18,9	11,1	5,5	3,9	3,3	2,8	2,2	2,2	1,7	1,7
	500	3,9	2,8	3,3	2,8	2,2	2,8	3,3	3,9	4,4	6,7	7,8	10,6	12,2	12,8	13,3	12,8	12,2	8,3	5,5	5,5	5,0	5,0	4,4	3,9
	700	4,4	4,4	4,4	4,4	4,4	3,9	3,3	3,3	3,3	3,9	4,4	5,0	5,5	8,3	10,0	10,6	11,1	7,2	4,4	4,4	4,4	4,4	4,4	4,4
O	100	−1,1	−1,7	−2,2	−1,1	0,0	1,7	3,3	7,8	11,1	17,8	22,2	25,0	26,7	18,9	12,2	7,8	4,4	2,8	1,1	0,5	0,0	0,0	−0,5	−0,5
	300	1,1	0,5	0,0	0,0	0,0	1,1	2,2	3,9	5,5	10,6	14,4	18,9	22,2	22,8	20,0	15,6	8,9	5,5	3,3	2,8	2,2	1,7	1,7	1,1
	500	3,9	3,9	3,3	3,3	3,3	3,3	3,3	3,9	4,4	5,5	6,7	9,4	11,1	13,9	15,6	15,0	14,4	10,6	7,8	6,7	6,1	5,5	5,0	4,4
	700	6,7	6,1	5,5	5,0	4,4	4,4	4,4	5,0	5,5	5,5	5,5	6,1	6,7	7,8	8,9	11,7	12,2	12,8	12,2	11,1	10,0	8,9	8,3	7,2
NO	100	−1,7	−2,2	−2,2	−1,1	0,0	1,7	3,3	5,5	6,7	10,6	13,3	18,3	22,2	20,6	18,9	10,0	3,3	2,2	1,1	0	−0,5	−0,5	−1,1	−1,1
	300	−1,1	−1,7	−2,2	−1,7	−1,1	0,0	1,1	3,3	4,4	5,5	6,7	11,7	16,7	17,2	17,8	11,7	6,7	4,4	3,3	2,2	1,7	0,5	0,0	−0,5
	500	2,8	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,8	3,3	5,0	6,7	9,4	11,1	11,7	12,2	7,8	4,4	3,9	3,9	3,3	3,3	2,8
	700	4,4	3,9	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,9	4,4	5,0	5,5	7,8	10,0	10,6	11,1	8,9	7,2	6,1	5,5	5,0

- ΔT_{em} for a dark roof, external temperature of 35ºC, internal temperature of 27ºC, daily ΔT of 11ºC for a July month at 15h on a 40º North Latitude. From *Manuale della Climatizzazione. - tab 3.18 "Differenza di temperatura equivalente (ºC).*

Tab. 3.18 - Differenza di temperatura equivalente (°C). Tetti irradiati o in ombra*. Valida per tetti di colore scuro, temperatura esterna 35 °C, temperatura interna 27 °C, escursione della temperatura esterna nelle 24 ore pari a 11 °C, mese di luglio e 40° di latitudine nord.**

Condizioni	Massa frontale (kg/m²)	Ora solare																							
		Mattino							Pomeriggio-Notte												Mattino				
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
Irradiato	50	*–2,2*	*–3,3*	*–3,9*	–2,8	*–0,5*	3,9	8,3	13,3	17,8	21,1	23,9	25,6	25,0	22,8	19,4	15,6	12,2	8,9	5,5	3,9	1,7	0,5	0,5	*–1,7*
	100	0,0	*–0,5*	*–1,1*	*–0,5*	1,1	5,0	8,9	12,8	16,7	20,0	22,8	23,9	23,9	22,2	19,4	16,7	13,9	11,1	8,3	6,7	4,4	3,3	2,2	1,1
	200	2,2	1,7	1,1	1,7	3,3	5,5	8,9	12,8	15,6	18,3	21,1	22,2	22,8	21,7	19,4	17,8	15,6	13,3	11,1	9,4	7,2	6,1	5,0	3,3
	300	5,0	4,4	3,3	3,9	4,4	6,1	8,9	12,2	15,0	17,2	19,4	21,1	21,7	21,1	20,0	18,9	17,2	15,6	13,9	12,2	10,0	8,9	7,2	6,1
	400	7,2	6,7	6,1	6,1	6,7	7,2	8,9	12,2	14,4	15,6	17,8	19,4	20,6	20,6	19,4	18,9	18,9	17,8	16,7	15,0	12,8	11,1	10,0	7,8
Ricoperto d'acqua	100	*–2,8*	*–1,1*	0,0	1,1	2,2	5,5	8,9	10,6	12,2	11,1	10,0	8,9	7,8	6,7	5,5	3,3	1,1	0,5	0,5	*–0,5*	*–1,1*	*–1,7*	*–2,2*	*–2,8*
	200	*–1,7*	*–1,1*	*–0,5*	–0,5	0,0	2,8	5,5	7,2	8,3	8,3	8,9	8,3	8,3	7,8	6,7	5,5	3,9	2,8	1,7	0,5	*–0,5*	*–1,1*	*–1,7*	*–1,7*
	300	*–0,5*	*–1,1*	*–1,1*	*–1,1*	*–1,1*	1,1	2,8	3,9	5,5	6,7	7,8	8,3	8,9	8,3	7,8	6,7	5,5	4,4	3,3	2,2	1,7	1,1	0,5	0,0
Bagnato	100	*–2,2*	*–1,1*	0,0	1,1	2,2	4,4	6,7	8,3	10,0	9,4	8,9	8,3	7,8	6,7	5,5	3,3	1,1	0,5	0,0	*–0,5*	*–1,1*	*–1,1*	*–1,7*	*–1,7*
	200	*–1,1*	*–1,1*	*–0,5*	*–0,5*	0,0	1,1	2,8	5,0	7,2	7,8	7,8	7,8	7,8	7,2	6,7	5,0	3,9	2,8	1,7	0,5	0,0	0,0	*–0,5*	*–0,5*
	300	*–0,5*	*–1,1*	*–1,1*	*–1,1*	*–1,1*	0,0	1,1	2,8	4,4	5,5	6,7	7,2	7,8	7,2	6,7	6,1	5,5	4,4	3,3	2,2	1,1	0,5	0,0	*–0,5*
In ombra	100	*–2,8*	*–1,8*	*–2,2*	*–1,1*	0,0	1,1	3,3	5,0	6,7	7,2	7,8	7,2	6,7	5,5	4,4	2,8	1,1	0,5	0,0	*–0,5*	*–1,7*	*–2,2*	*–2,8*	*–2,8*
	200	*–2,8*	*–2,8*	*–2,2*	*–1,7*	*–1,1*	0,0	1,1	2,8	4,4	5,5	6,7	7,2	6,7	6,1	5,5	4,4	3,3	2,2	1,1	0,0	*–0,5*	*–1,7*	*–2,2*	*–2,8*
	300	*–1,7*	*–1,7*	*–1,1*	*–1,1*	*–1,1*	*–0,5*	0,0	1,1	2,2	3,3	4,4	5,0	5,5	5,5	5,5	5,0	4,4	3,3	2,2	1,1	0,5	0,0	*–0,5*	*–1,1*
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
		Mattino							Pomeriggio-Notte												Mattino				
		Ora solare																							

Relazione: Carichi per trasmissione attraverso il tetto W = superficie (m²) × (differenza di temperatura equivalente) × (coefficiente di trasmissione globale).
* Se il sottotetto è ventilato o se il soffitto è isolato, assumere il 75% dei valori in tabella. Per i tetti inclinati, considerare la superficie della proiezione orizzontale.
** Per condizioni diverse, applicare le correzioni riportate nelle note della tabella 3.17.

$$\Delta t_e = a + \Delta t_{es} + b \frac{R_s}{R_m} (\Delta t_{em} - \Delta t_{es})$$

- α intended as Correction Value for ΔT_{eq} calculation on different ΔT_{em} conditions: when the Exterior minus interior temperature difference has a value other than 8 ºC from *Tab.3.19 – "Correzioni delle differenze di temperatura equivalente" – Manuale della Climatizzazione*, in Celsius.

Tab. 3.19 - Correzioni delle differenze di temperatura equivalente (°C).

Temperatura esterna alle ore 15, per il mese considerato, meno temperatura interna (°C)	Escursione della temperatura esterna nelle 24 ore																	
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
16	–21,2	–21,7	–22,3	–22,8	–23,3	–23,8	–24,2	–24,7	–25,1	–25,6	–26,0	–26,5	–27,0	–27,4	–27,9	–28,8	–29,3	–29,8
12	–17,2	–17,7	–18,3	–18,8	–19,3	–19,8	–20,2	–20,7	–21,1	–21,6	–22,0	–22,5	–23,0	–23,4	–23,9	–24,8	–25,3	–25,8
8	–13,2	–13,7	–14,3	–14,8	–15,3	–15,8	–16,2	–16,7	–17,1	–17,6	–18,0	–18,5	–19,0	–19,4	–19,9	–20,8	–21,3	–21,8
4	–9,2	–9,7	–10,3	–10,8	–11,3	–11,8	–12,2	–12,7	–13,1	–13,6	–14,0	–14,5	–15,0	–15,4	–15,9	–16,8	–17,3	–17,8
0	–5,0	–5,5	–6,1	–6,6	–7,1	–7,6	–8,0	–8,5	–8,9	–9,4	–9,8	–10,3	–10,8	–11,2	–11,7	–12,6	–13,1	–13,6
+2	–3,1	–3,6	–4,2	–4,7	–5,2	–5,6	–6,1	–6,6	–7,0	–7,5	–7,9	–8,4	–8,9	–9,3	–9,8	–10,6	–11,1	–11,7
+4	–1,1	–1,6	–2,2	–2,7	–3,2	–3,6	–4,1	–4,6	–5,0	–5,5	–5,9	–6,4	–6,9	–7,3	–7,8	–8,6	–9,1	–9,7
+6	0,8	0,3	–0,3	–0,8	–1,3	–1,7	–2,2	–2,7	–3,1	–3,6	–4,0	–4,5	–5,0	–5,4	–5,9	–6,7	–7,2	–7,8
+8	2,8	2,3	1,7	1,2	0,7	0,3	0,0	–0,7	–1,1	–1,6	–2,0	–2,5	–3,0	–3,4	–3,9	–4,7	–5,2	–5,8
+10	4,7	4,2	3,6	3,1	2,6	2,2	1,7	1,2	0,8	0,3	–0,1	–0,6	–1,1	–1,5	–2,0	–2,8	–3,3	–3,9
+12	6,8	6,3	5,7	5,2	4,7	4,3	3,8	3,3	2,9	2,4	1,8	1,3	0,8	0,4	–0,1	–0,7	–1,2	–1,8
+14	8,8	8,3	7,7	7,2	6,7	6,3	5,8	5,3	4,9	4,4	3,8	3,3	2,8	2,4	1,9	1,3	0,8	0,2
+16	10,8	10,3	9,7	9,2	8,7	8,3	7,8	7,3	6,9	6,4	5,8	5,3	4,8	4,4	3,9	3,3	2,8	2,2
+18	12,8	12,3	11,7	11,2	10,7	10,3	9,8	9,3	8,9	8,4	7,8	7,3	6,8	6,4	5,9	5,3	4,8	4,2
+20	14,8	14,3	13,7	13,2	12,7	12,3	11,8	11,3	10,9	10,4	9,8	9,3	8,8	8,4	7,9	7,3	6,8	6,2
+22	16,9	16,4	15,8	15,3	14,8	14,4	13,9	13,4	13,0	12,5	11,9	11,4	10,9	10,5	10,0	9,4	8,9	8,3

- ΔT_{es} as Equivalent temperature difference under shady condition from *Tab. 3.17- Differenza di temperature equivalente per muri irradiati o in ombra – Manuale della Climatizzazione*, in Celsius.

Orientamento	Massa frontale *** (kg/m²)	Ora solare																							
		Mattino							Pomeriggio-Notte												Mattino				
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
	100	−1,7	−1,7	−2,2	−1,7	−1,1	0,5	2,2	4,4	5,5	6,7	7,8	7,2	6,7	5,5	4,4	3,3	2,2	1,1	0,0	0	−0,5	−0,5	−1,1	−1,1
N (in ombra)	300	−1,7	−1,7	−2,2	−1,7	−1,1	−0,5	0,0	1,7	3,3	4,4	5,5	6,1	6,7	6,7	6,7	5,5	4,4	3,3	2,2	1,1	0,5	0,0	−0,5	−1,1
	500	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,5	1,1	1,7	2,2	2,8	2,8	2,8	4,4	3,9	3,3	2,8	2,2	1,7	1,7	1,1	1,1	0,5
	700	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	1,1	1,7	2,2	2,8	3,3	3,9	4,4	3,9	3,3	2,2	1,7	1,1	1,1	0,5

- *b* as colour factor, (1 for dark, 0.78 for medium and 0.55 for light colour), unitless.

- R_m as the maximum solar radiation from all the orientations in July at 40º Latitude – *Tab. 3.22. Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice - Manuale della Climatizzazione.*

Tab. 3.22 - Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice* (W/m²).

Latitudine nord	Mese	Orientamento (latitudine nord)									Mese	Latitudine sud
		N**	NE	E	SE	S	SO	O	NO	Orizz.		
	Luglio e maggio	47	400	517	394	218	394	517	400	737	Nov. e gennaio	
	Agosto e aprile	34	321	511	460	321	460	511	321	675	Ottobre e febbraio	
40°	Settembre e marzo	28	183	470	510	441	510	470	183	577	Settembre e marzo	40°
	Ottobre e febbraio	22	109	384	514	511	514	384	109	406	Agosto e aprile	
	Nov. e gennaio	15	37	315	492	524	492	315	37	325	Luglio e maggio	
	Dicembre	15	31	271	467	520	467	271	31	268	Giugno	

- R_S as the maximum solar radiation specific for the wall orientation at building's latitude during the month of analysis – *Tab. 3.22. Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice - Manuale della Climatizzazione.*

Tab. 3.22 - Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice* (W/m²).

Latitudine nord	Mese	Orientamento (latitudine nord)									Mese	Latitudine sud
		N**	NE	E	SE	S	SO	O	NO	Orizz.		
	Giugno	186	492	463	131	44	131	463	492	712	Dicembre	
	Luglio e maggio	151	482	479	164	44	164	479	482	734	Nov. e gennaio	
	Agosto e aprile	78	444	514	249	44	249	514	444	773	Ottobre e febbraio	
0°	Settembre e marzo	31	372	526	372	44	372	526	372	789	Settembre e marzo	0°
	Ottobre e febbraio	31	249	514	444	107	444	514	249	773	Agosto e aprile	
	Nov. e gennaio	31	164	479	482	211	482	479	164	734	Luglio e maggio	
	Dicembre	31	131	463	492	258	492	463	131	712	Giugno	
	Giugno	126	482	489	173	44	173	489	482	767	Dicembre	
	Luglio e maggio	94	467	498	208	44	208	498	467	778	Nov. e gennaio	
	Agosto e aprile	41	410	514	296	44	296	514	410	789	Ottobre e febbraio	
10°	Settembre e marzo	31	325	517	400	87	400	517	325	778	Settembre e marzo	10°
	Ottobre e febbraio	31	208	489	470	230	470	488	208	725	Agosto e aprile	
	Nov. e gennaio	28	116	450	507	334	318	450	116	662	Luglio e maggio	
	Dicembre	28	87	432	514	377	514	432	87	636	Giugno	
	Giugno	81	485	504	230	44	230	504	485	789	Dicembre	
	Luglio e maggio	59	435	514	268	44	268	514	435	791	Nov. e gennaio	
	Agosto e aprile	34	372	520	356	81	356	520	372	778	Ottobre e febbraio	
20°	Settembre e marzo	31	273	514	441	205	441	514	273	734	Settembre e marzo	20°
	Ottobre e febbraio	28	164	463	504	350	504	463	164	656	Agosto e aprile	
	Nov. e gennaio	24	81	404	517	444	517	404	81	568	Luglio e maggio	
	Dicembre	24	56	382	526	470	526	382	56	536	Giugno	
	Giugno	63	439	507	284	66	284	507	439	789	Dicembre	
	Luglio e maggio	50	413	517	315	94	315	517	413	776	Nov. e gennaio	
	Agosto e aprile	34	340	520	406	198	406	520	340	741	Ottobre e febbraio	
30°	Settembre e marzo	28	284	498	479	330	479	498	284	668	Settembre e marzo	30°
	Ottobre e febbraio	24	122	426	514	457	514	426	122	564	Agosto e aprile	
	Nov. e gennaio	22	50	365	511	502	511	365	50	457	Luglio e maggio	
	Dicembre	19	37	330	511	514	511	330	37	413	Giugno	
	Giugno	54	419	511	350	170	350	511	419	747	Dicembre	
	Luglio e maggio	47	400	517	394	218	394	517	400	737	Nov. e gennaio	
	Agosto e aprile	34	321	511	460	321	460	511	321	675	Ottobre e febbraio	
40°	Settembre e marzo	28	183	470	510	441	510	470	183	577	Settembre e marzo	40°
	Ottobre e febbraio	22	109	384	514	511	514	384	109	406	Agosto e aprile	
	Nov. e gennaio	15	37	315	492	524	492	315	37	325	Luglio e maggio	
	Dicembre	15	31	271	467	520	467	271	31	268	Giugno	
	Giugno	50	397	517	426	293	426	517	397	694	Dicembre	
	Luglio e maggio	44	369	514	450	334	450	514	369	666	Nov. e gennaio	
	Agosto e aprile	34	296	498	495	435	495	498	296	583	Ottobre e febbraio	
50°	Settembre e marzo	24	183	435	514	498	514	435	183	467	Settembre e marzo	50°
	Ottobre e febbraio	15	91	330	495	526	495	330	91	296	Agosto e aprile	
	Nov. e gennaio	12	28	201	400	482	400	201	28	166	Luglio e maggio	
	Dicembre	9	22	148	365	444	365	148	22	126	Giugno	

- I_{max} as the Maximum Irradiation on the window surface. It needs to be taken for the window orientation, project's latitude, at the month of the analysis, in W/m^2. *Tab. 3.21. Carichi termici dovuti alla radiazione solare attraverso il vetro comune* - *Manuale della Climatizzazione*. Here there are the values for 40º and 50º latitude.

Tab. 3.21 - *(Continua dalla pagina precedente).*

40° Latitudine 40°

40° Latitudine nord		Ora solare													40° Latitudine sud	
Periodo	Orientamento	6	7	8	9	10	11	12	13	14	15	16	17	18	Orientamento	Periodo
21 giugno	N	101	63	38	41	44	44	44	44	44	41	38	63	101	S	22 dicembre
	N E	372	419	353	230	95	44	44	44	44	41	38	32	19	S E	
	E	397	508	511	448	300	139	44	44	44	41	38	32	19	E	
	S E	161	278	344	350	312	224	107	44	44	41	38	32	19	N E	
	S	19	32	38	60	110	139	170	139	110	60	38	32	19	N	
	S O	19	32	38	41	44	44	107	224	312	350	344	278	161	N O	
	O	19	32	38	41	44	44	44	139	300	448	511	508	397	O	
	N O	19	32	38	41	44	44	44	44	95	230	353	419	372	S O	
	Orizzontale	98	259	423	565	662	732	747	732	662	565	423	259	98	Orizzontale	
23 luglio e 21 maggio	N	76	44	38	41	44	44	44	44	44	41	38	44	76	S	21 gennaio e 21 novembre
	N E	334	401	331	208	82	44	44	44	44	41	38	32	16	S E	
	E	372	508	517	454	309	136	44	44	44	41	38	32	16	E	
	S E	170	303	375	394	347	259	132	47	44	41	38	32	16	N E	
	S	16	32	41	82	139	199	218	199	139	82	41	32	16	N	
	S O	16	32	38	41	44	47	132	259	347	394	375	303	170	N O	
	O	16	32	38	41	44	44	44	136	309	454	517	508	372	O	
	N O	16	32	38	41	44	44	44	44	82	208	331	401	334	S O	
	Orizzontale	76	230	397	539	640	710	735	710	640	539	397	230	76	Orizzontale	
24 agosto e 20 aprile	N	22	25	35	41	44	44	44	44	44	41	35	25	22	S	20 febbraio e 23 ottobre
	N E	214	322	259	145	50	44	44	44	44	41	35	25	9	S E	
	E	265	464	511	457	319	142	44	44	44	41	35	25	9	E	
	S E	151	331	435	460	438	337	208	79	44	41	35	25	9	N E	
	S	9	25	76	161	281	306	322	306	281	161	76	25	9	N	
	S O	9	25	35	41	44	79	208	337	438	460	435	331	151	N O	
	O	9	25	35	41	44	44	44	142	319	457	511	464	265	O	
	N O	9	25	35	41	44	44	44	44	50	145	259	322	214	S O	
	Orizzontale	28	148	315	473	583	647	675	647	583	473	315	148	28	Orizzontale	
22 settembre e 22 marzo	N	0	16	28	38	41	41	44	41	41	38	28	16	0	S	22 marzo e 22 settembre
	N E	0	161	183	82	41	41	44	41	41	38	28	16	0	S E	
	E	0	366	470	438	312	142	44	41	41	38	28	16	0	E	
	S E	0	300	454	511	495	419	284	129	44	38	28	16	0	N E	
	S	0	38	139	255	347	385	442	385	347	255	139	38	0	N	
	S O	0	16	28	38	44	129	284	419	495	511	454	300	0	N O	
	O	0	16	28	38	41	41	44	142	312	438	470	366	0	O	
	N O	0	16	28	38	41	41	44	41	41	82	183	161	0	S O	
	Orizzontale	0	66	211	391	483	555	577	555	483	391	211	66	0	Orizzontale	
23 ottobre e 20 febbraio	N	0	6	19	32	35	38	38	38	35	32	19	6	0	S	20 aprile e 24 agosto
	N E	0	110	104	38	35	38	38	38	35	32	19	6	0	S E	
	E	0	268	369	385	278	123	38	38	35	32	19	6	0	E	
	S E	0	255	416	508	514	454	337	199	63	32	19	6	0	N E	
	S	0	66	186	328	432	486	511	486	432	328	186	66	0	N	
	S O	0	6	19	32	63	199	337	454	514	508	416	255	0	N O	
	O	0	6	19	32	35	38	38	123	278	385	369	268	0	O	
	N O	0	6	19	32	35	38	38	38	35	38	104	110	0	S O	
	Orizzontale	0	25	91	202	319	388	407	388	319	202	91	25	0	Orizzontale	
21 novembre e 21 gennaio	N	0	0	9	22	28	32	35	32	28	22	9	0	0	S	21 maggio e 23 luglio
	N E	0	0	38	22	28	32	35	32	28	22	9	0	0	S E	
	E	0	0	287	315	233	104	35	32	28	22	9	0	0	E	
	S E	0	0	344	454	492	454	366	221	85	22	9	0	0	N E	
	S	0	0	186	328	438	498	524	498	438	328	186	0	0	N	
	S O	0	0	9	22	85	221	366	454	492	454	344	0	0	N O	
	O	0	0	9	22	28	32	35	104	233	315	287	0	0	O	
	N O	0	0	9	22	28	32	35	32	28	22	38	0	0	S O	
	Orizzontale	0	0	50	136	230	290	325	290	230	136	50	0	0	Orizzontale	
22 dicembre	N	0	0	6	19	28	32	32	32	28	19	6	0	0	S	21 giugno
	N E	0	0	22	19	28	32	32	32	28	19	6	0	0	S E	
	E	0	0	227	271	214	98	32	32	28	19	6	0	0	E	
	S E	0	0	278	423	467	448	363	230	95	22	6	0	0	N E	
	S	0	0	161	312	423	498	520	498	423	312	161	0	0	N	
	S O	0	0	6	22	95	230	363	448	467	423	278	0	0	N O	
	O	0	0	6	19	28	32	32	98	214	271	227	0	0	O	
	N O	0	0	6	19	28	32	32	32	28	19	22	0	0	S O	
	Orizzontale	0	0	25	101	173	240	268	240	173	101	25	0	0	Orizzontale	

Tab. 3.21 - *(Continua dalla pagina precedente).*

50° Latitudine 50°

50° Latitudine nord		Ora solare													50° Latitudine sud	
Periodo	Orientamento	6	7	8	9	10	11	12	13	14	15	16	17	18	Orientamento	Periodo
S E 21 giugno	N	91	38	38	41	44	44	44	44	44	41	38	38	91	S	22 dicembre
	N E	397	394	296	158	50	44	44	44	44	41	38	32	25	S E	
	E	438	517	511	429	296	129	44	44	44	41	38	32	25	E	
	202	322	397	426	391	309	192	73	44	41	38	32	25	N E		
	S	25	32	50	123	214	274	293	274	214	123	50	32	25	N	
	S O	25	32	38	41	44	73	192	309	391	426	397	322	202	N O	
	O	25	32	38	41	44	44	44	129	296	429	511	517	438	O	
	N O	25	32	38	41	44	44	44	44	50	158	296	394	397	S O	
	Orizzontale	139	271	419	546	621	675	694	675	621	546	419	271	139	Orizzontale	
23 luglio e 21 maggio	N	66	35	38	41	44	44	44	44	44	41	38	35	66	S	21 gennaio e 21 novembre
	N E	360	369	274	139	47	44	44	44	44	41	38	32	19	S E	
	E	413	508	514	445	303	136	44	44	44	41	38	32	19	E	
	S E	205	337	423	451	429	344	221	82	44	41	38	32	19	N E	
	S	19	32	66	158	252	309	334	309	252	158	66	32	19	N	
	S O	19	32	38	41	44	82	221	344	429	451	423	337	205	N O	
	O	19	32	38	41	44	44	44	136	303	445	514	508	413	O	
	N O	19	32	38	41	44	44	44	44	47	139	274	369	360	S O	
	Orizzontale	104	237	375	501	593	647	665	647	593	501	375	237	104	Orizzontale	
24 agosto e 20 aprile	N	25	25	32	38	41	44	44	44	41	38	32	25	25	S	20 febbraio e 23 ottobre
	N E	240	296	221	98	41	44	44	44	41	38	32	25	13	S E	
	E	296	457	498	445	309	142	44	44	41	38	32	25	13	E	
	S E	167	350	454	495	483	416	281	126	41	38	32	25	13	N E	
	S	13	28	114	230	331	410	435	410	331	230	114	28	13	N	
	S O	13	25	32	38	41	126	281	416	483	495	454	350	167	N O	
	O	13	25	32	38	41	44	44	142	309	445	498	457	296	O	
	N O	13	25	32	38	41	44	44	44	41	98	221	296	240	S O	
	Orizzontale	41	145	281	413	505	565	583	565	505	413	281	145	41	Orizzontale	

22 settembre e 22 marzo	N	0	13	25	32	38	38	**38**	38	38	32	25	13	0	S	22 marzo e 22 settembre
	N E	0	**183**	145	50	38	38	38	38	38	32	25	13	0	S E	
	E	0	322	**435**	410	293	136	38	38	38	32	25	13	0	E	
	S E	0	271	438	511	*514*	457	331	177	54	32	25	13	0	N E	
	S	0	35	161	293	413	473	**498**	473	413	293	161	35	0	N	
	S O	0	13	25	32	54	177	331	457	*514*	511	438	271	0	N O	
	O	0	13	25	32	38	38	38	136	293	410	**435**	322	0	O	
	N O	0	13	25	32	38	38	38	38	38	50	145	**183**	0	S O	
	Orizzontale	0	47	155	278	372	442	**467**	442	372	278	156	47	0	Orizzontale	
23 ottobre e 20 febbraio	N	0	0	13	22	28	32	**35**	32	28	22	13	0	0	S	20 aprile e 24 agosto
	N E	0	**91**	63	22	28	32	35	32	28	22	13	0	0	S E	
	E	0	230	312	**331**	249	110	35	32	28	22	13	0	0	E	
	S E	0	218	350	457	**495**	454	363	218	76	22	13	0	0	N E	
	S	0	54	167	312	432	495	*527*	495	432	312	167	54	0	N	
	S O	0	0	13	22	76	218	363	454	**495**	457	350	218	0	N O	
	O	0	0	13	22	28	32	35	110	249	**331**	312	230	0	O	
	N O	0	0	13	22	28	32	35	32	28	22	63	**91**	0	S O	
	Orizzontale	0	6	60	142	227	271	**296**	271	227	142	60	6	0	Orizzontale	
21 novembre e 21 gennaio	N	0	0	3	13	19	25	**28**	25	19	13	3	0	0	S	21 maggio e 23 luglio
	N E	0	0	16	13	19	25	**28**	25	19	13	3	0	0	S E	
	E	0	0	161	**202**	180	88	28	25	19	13	3	0	0	E	
	S E	0	0	196	300	**401**	**401**	337	211	66	13	3	0	0	N E	
	S	0	0	107	221	366	451	**483**	451	366	221	107	0	0	N	
	S O	0	0	3	13	66	211	337	**401**	**401**	300	196	0	0	N O	
	O	0	0	3	13	19	25	28	88	180	**202**	161	0	0	O	
	N O	0	0	3	13	19	25	**28**	25	19	13	16	0	0	S O	
	Orizzontale	0	0	13	41	95	148	**167**	148	95	41	13	0	0	Orizzontale	
22 dicembre	N	0	0	0	9	16	19	22	19	16	9	0	0	0	S	21 giugno
	N E	0	0	0	9	16	19	22	19	16	9	0	0	0	S E	
	E	0	0	0	85	**148**	73	22	19	16	9	0	0	0	E	
	S E	0	0	0	129	337	**366**	315	196	79	9	0	0	0	N E	
	S	0	0	0	98	312	413	**445**	413	312	98	0	0	0	N	
	S O	0	0	0	9	79	196	315	**366**	337	129	0	0	0	N O	
	O	0	0	0	9	16	19	22	73	**148**	85	0	0	0	O	
	N O	0	0	0	9	16	19	**22**	19	16	9	0	0	0	S O	
	Orizzontale	0	0	0	16	60	104	**126**	104	60	16	0	0	0	Orizzontale	

- For A_{cc} from *Tab.3.28 – Coefficienti d'accumulo dei carichi termini dovuti alla radiazione solare attraverso i vetri (12 ore di funzionamento a temperatura interna costante)* **-** *Manuale della Climatizzazione.*

Tab. 3.28 - Coefficienti d'accumulo dei carichi termici dovuti alla radiazione solare attraverso i vetri (12 ore di funzionamento a temperatura interna costante +).

Orientamento (latitudine nord)	Massa efficace dell'ambiente (x) (kg/m²)	Schermi interni*												Senza schermi o con schermi esterni++												Orientamento (latitudine sud)
		Ora solare																								
		Mattino							Pomeriggio					Mattino							Pomeriggio					
		6	7	8	9	10	11	12	13	14	15	16	17	6	7	8	9	10	11	12	13	14	15	16	17	
NE	750 e più	0,59	0,67	0,62	0,49	0,33	0,27	0,25	0,24	0,22	0,21	0,20	0,17	0,34	0,42	0,47	0,45	0,42	0,39	0,36	0,33	0,30	0,29	0,26	0,25	SE
	500	0,59	0,68	0,64	0,52	0,35	0,29	0,24	0,23	0,20	0,19	0,17	0,15	0,35	0,45	0,50	0,49	0,45	0,42	0,34	0,30	0,27	0,26	0,23	0,20	
	150	0,62	0,80	0,75	0,60	0,37	0,25	0,19	0,17	0,15	0,13	0,12	0,11	0,04	0,62	0,69	0,64	0,48	0,34	0,27	0,22	0,18	0,16	0,14	0,12	
E	750 e più	0,51	0,66	0,71	0,67	0,57	0,40	0,29	0,26	0,25	0,23	0,21	0,19	0,36	0,44	0,50	0,53	0,53	0,50	0,44	0,39	0,36	0,34	0,30	0,28	E
	500	0,52	0,67	0,73	0,70	0,58	0,40	0,29	0,26	0,24	0,21	0,19	0,16	0,34	0,44	0,54	0,58	0,57	0,51	0,44	0,39	0,34	0,31	0,28	0,24	
	150	0,53	0,74	0,82	0,81	0,65	0,43	0,25	0,19	0,16	0,14	0,11	0,09	0,36	0,56	0,71	0,76	0,70	0,54	0,39	0,28	0,23	0,18	0,15	0,12	
SE	750 e più	0,20	0,42	0,59	0,70	0,74	0,71	0,61	0,48	0,33	0,30	0,26	0,24	0,34	0,37	0,43	0,50	0,54	0,58	0,57	0,55	0,50	0,45	0,41	0,37	NE
	500	0,18	0,40	0,57	0,70	0,75	0,72	0,63	0,49	0,34	0,28	0,25	0,21	0,29	0,33	0,41	0,51	0,58	0,61	0,61	0,56	0,49	0,44	0,37	0,33	
	150	0,09	0,35	0,61	0,78	0,86	0,82	0,69	0,50	0,30	0,20	0,17	0,13	0,14	0,27	0,47	0,64	0,75	0,79	0,73	0,61	0,45	0,32	0,23	0,18	
S	750 e più	0,28	0,25	0,40	0,53	0,64	0,72	0,77	0,77	0,73	0,67	0,49	0,31	0,47	0,43	0,42	0,46	0,51	0,56	0,61	0,65	0,66	0,65	0,61	0,54	N
	500	0,26	0,22	0,38	0,51	0,64	0,73	0,79	0,79	0,77	0,65	0,51	0,31	0,44	0,37	0,39	0,43	0,50	0,57	0,64	0,68	0,70	0,68	0,63	0,53	
	150	0,21	0,29	0,48	0,67	0,79	0,88	0,89	0,83	0,56	0,50	0,24	0,16	0,28	0,19	0,25	0,38	0,54	0,68	0,78	0,84	0,82	0,76	0,61	0,42	
SO	750 e più	0,31	0,27	0,27	0,26	0,25	0,27	0,50	0,63	0,72	0,74	0,69	0,54	0,51	0,44	0,40	0,37	0,34	0,36	0,41	0,47	0,54	0,57	0,60	0,58	NO
	500	0,33	0,28	0,25	0,23	0,23	0,35	0,50	0,64	0,74	0,77	0,70	0,55	0,53	0,44	0,37	0,35	0,31	0,33	0,39	0,46	0,50	0,62	0,64	0,60	
	150	0,29	0,21	0,18	0,15	0,14	0,27	0,50	0,69	0,82	0,87	0,79	0,60	0,48	0,32	0,25	0,20	0,17	0,19	0,39	0,56	0,70	0,80	0,79	0,69	
O	750 e più	0,63	0,31	0,28	0,27	0,25	0,24	0,22	0,29	0,46	0,61	0,71	0,72	0,56	0,49	0,44	0,39	0,36	0,33	0,31	0,31	0,35	0,42	0,49	0,54	O
	500	0,67	0,33	0,28	0,26	0,24	0,22	0,20	0,28	0,44	0,61	0,72	0,73	0,60	0,52	0,44	0,39	0,34	0,31	0,29	0,28	0,33	0,43	0,51	0,57	
	150	0,77	0,34	0,25	0,20	0,17	0,14	0,13	0,22	0,44	0,67	0,82	0,85	0,77	0,56	0,38	0,28	0,22	0,18	0,16	0,19	0,33	0,52	0,69	0,77	
NO	750 e più	0,68	0,28	0,27	0,25	0,23	0,22	0,20	0,19	0,24	0,41	0,56	0,67	0,49	0,44	0,39	0,36	0,33	0,30	0,28	0,26	0,26	0,30	0,37	0,44	SO
	500	0,71	0,31	0,27	0,24	0,22	0,21	0,19	0,18	0,23	0,40	0,58	0,70	0,54	0,49	0,41	0,35	0,31	0,28	0,25	0,23	0,24	0,30	0,39	0,48	
	150	0,82	0,33	0,25	0,20	0,18	0,15	0,14	0,13	0,19	0,41	0,64	0,80	0,75	0,53	0,36	0,28	0,24	0,19	0,17	0,15	0,17	0,30	0,50	0,66	
N e in ombra	750 e più	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,75	0,75	0,79	0,83	0,84	0,86	0,88	0,88	0,91	0,92	0,93	0,93	S e in ombra
	500	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,81	0,84	0,86	0,89	0,91	0,93	0,93	0,94	0,94	0,95	0,95	0,95	
	150	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	

- $F_{shading+screen}$ from Tab 3.23 – Coefficienti correttivi di riduzione per I vetri con o senza schermi - *Manuale della Climatizzazione.*

Tab. 3.23 - Coefficienti correttivi di riduzione per i vetri con o senza schermi*.

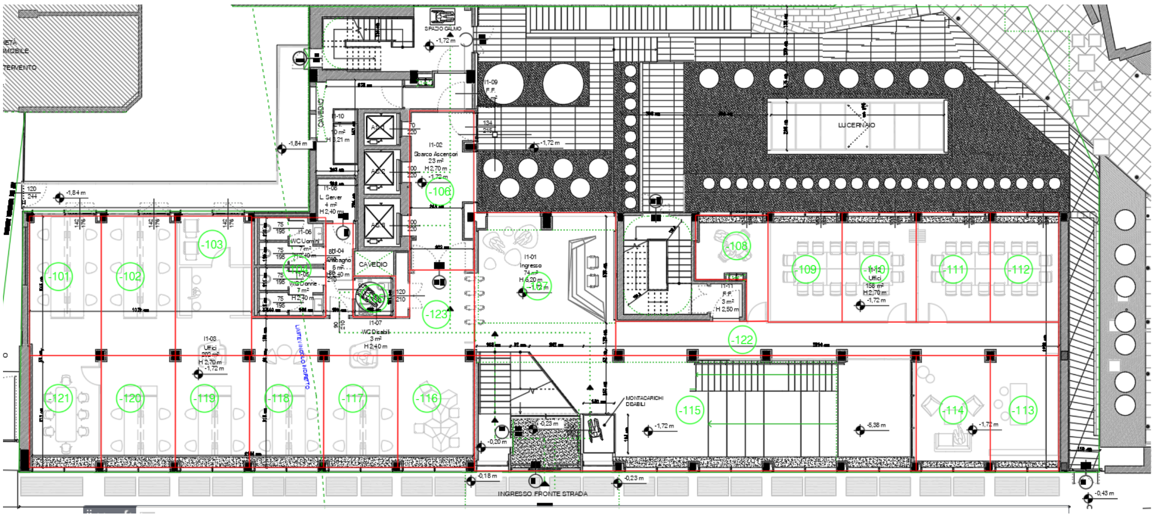
Tipo di vetro	Senza schermo	Tende alla veneziana interne* Lamelle a 45° orizzontali o verticali o schermi in tela			Tende alla veneziana esterne Lamelle a 45° orizzontali		Schermo esterno Lamelle a 17° + orizzontali		Schermo in tela esterno Circolazione d'aria in alto e sui lati #	
		Colore chiaro	Colore medio	Colore scuro	Colore chiaro	Esterno chiaro Int. scuro	Colore medio**	Colore scuro^x	Colore chiaro	Colore medio o scuro
Vetro semplice comune	1,00	0,56	0,65	0,75	0,15	0,13	0,22	0,15	0,20	0,25
Vetro semplice 6 mm	0,94	0,56	0,65	0,74	0,14	0,12	0,21	0,14	0,19	0,24
Vetro assorbente ++										
Coeff. d'assorbimento 0,40÷0,48	0,80	0,56	0,62	0,72	0,12	0,11	0,18	0,12	0,16	0,20
Coeff. d'assorbimento 0,49÷0,56	0,73	0,53	0,59	0,62	0,11	0,10	0,16	0,11	0,15	0,18
Coeff. d'assorbimento 0,57÷0,70	0,62	0,51	0,54	0,56	0,10	0,10	0,14	0,10	0,12	0,16
Doppio vetro										
Vetro comune	0,90	0,54	0,61	0,67	0,14	0,12	0,20	0,14	0,18	0,22
Vetro 6 mm	0,80	0,52	0,59	0,65	0,12	0,11	0,18	0,12	0,16	0,20
Vetro interno comune Vetro esterno assorbente 0,48÷0,56	0,52	0,36	0,39	0,43	0,10	0,10	0,11	0,10	0,10	0,13
Vetro interno da 6 mm Vetro esterno assorbente 0,48÷0,56	0,50	0,36	0,39	0,43	0,10	0,10	0,11	0,10	0,10	0,12
Triplo vetro										
Vetro comune	0,83	0,48	0,56	0,64	0,12	0,11	0,18	0,12	0,16	0,20
Vetro da 6 mm	0,69	0,47	0,52	0,57	0,10	0,10	0,15	0,10	0,14	0,17
Vetro riflettente										
Colore chiaro	0,28									
Colore medio	0,39									
Colore scuro	0,50									
Vetri colorati xx										
Ambrati	0,70									
Rosso cupo	0,56									
Blu scuro	0,60									
Grigio scuro	0,32									
Grigio-verde	0,46									
Opalescente chiaro	0,43									
Opalescente scuro	0,37									

- For F_{fog}, F_{frame}, $F_{dew\text{-}point}$, $F_{altitude}$ from *Coefficienti di correzione* of *Tab. 3.22. Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice - Manuale della Climatizzazione.*

Coefficienti di correzione	Telaio metallico o senza telaio	Foschia	Altitudine	Temperatura di rugiada superiore a 19,5 °C	Temperatura di rugiada inferiore a 19,5 °C	Latitudine sud Dicembre o gennaio
	× 1/0,85 o 1,17	– 15% (max)	+ 0,7% per 300 m	– 13% per 10 °C	+ 13% per 10 °C	+ 7%

* Valori ricavati dalla tabella 3.21.
** I carichi dovuti ai vetri orientati a nord (latitudine nord) o a sud (latitudine sud) sono principalmente dovuti all'irraggiamento diffuso che resta sensibilmente costante durante tutto il giorno. I valori indicati sono medie dei valori rilevati su 12 ore (dalle 6 alle 18). Nelle tabelle da 3.24 a 3.28 che danno i coefficienti d'attenuazione, si suppone che i carichi dovuti alle superfici vetrate nord (o sud) siano costanti e si possano applicare gli stessi coefficienti dell'illuminazione.

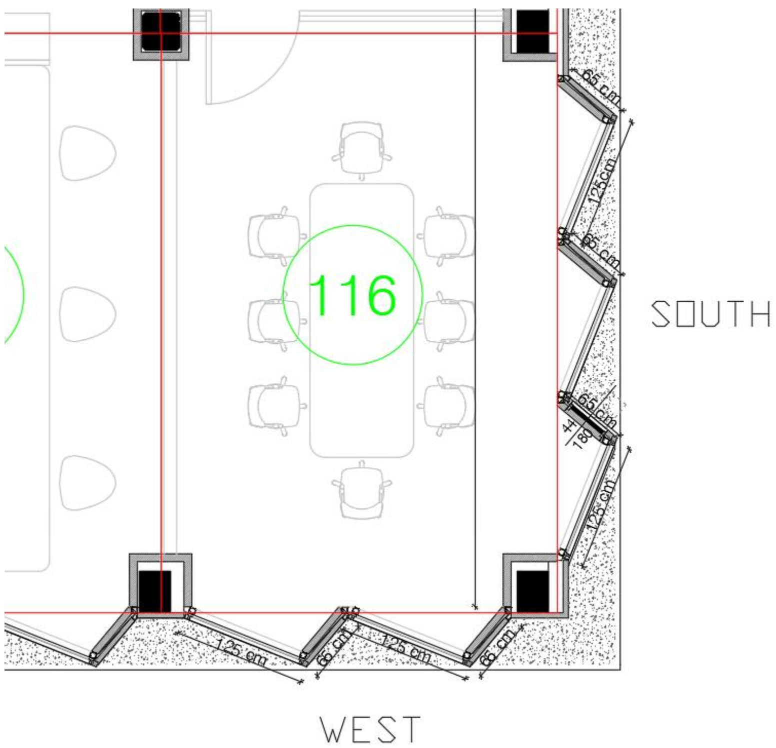
1.7. Peak heating needs estimation for winter



Floor plan of the building of analysis – Porta Vigentina project- Lombardini 22.

On this chapter is applied the explained Carrier method to estimate the thermal heating needs for winter condition on a real project, designed by Lombardini 22.

The first step is to make the transition from architectural spaces into thermal zones, to make this, the engineer needs to have in mind which areas of the plan are supposed to be kept in comfort conditions (air temperature and relative humidity) and which not. On this specific project, since it is an Office building (located in the city of Milan), offices, corridors, meeting rooms and WC will be subjected to thermal conditioning, while stairs, technical rooms, shafts and elevators areas not.



Individual thermal zone 116, with its boundaries on red colour

On winter scenario, the heat transfer is considered entirely as the conduction from inside to the outside of the thermal zone. Following the definition of thermal transmittance:

$$\dot{Q} = U.A.\Delta T$$

On winter, it states the heat flux that goes from the interior of a conditioned thermal zone, with a 20°C set point, either to the external air at -5°C, or to the internal air of a non-conditioned spaces.

Here there is an example of conduction calculation for the thermal space 116, previously showed up on *Picture 1.2,* with the spreadsheet used as tool:

Locale n°	116					
26	1		1		INVERNO	
69	2.7					trasm.
	esp.	%	mq.	K	ΔT	W
Parete cieca	N	20		0.26	25	0
Parete finestrata	N	20		1.25	25	0
Parete finestrata (ombra	N	20		1.25	25	0
Porta	N	20		2.00	25	0
Parete cieca	E	15		0.26	25	0
Parete finestrata	E	15		1.25	25	0
Porta	E	15		2.00	25	0
Parete cieca	S	5		0.26	25	0
Parete finestrata	S	5		1.25	25	0
Porta	S	5		2.00	25	0
Parete cieca	W	10	2.10	0.26	25	14.8
Parete finestrata	W	10		1.25	25	0.0
Porta	W	10		2.00	25	0.0
Parete cieca	NE	20		0.26	25	0.0
Parete finestrata	NE	20		1.25	25	0.0
Porta	NE	20		2.00	25	0.0
Parete cieca	SE	10	6.83	0.26	25	48.2
Parete finestrata	SE	10		1.25	25	0.0
Porta	SE	10		2.00	25	0.0
Parete cieca	SW	5	5.86	0.26	25	39.5
Parete finestrata	SW	5	11.81	1.25	25	387.6
Porta	SW	5		2.00	25	0
Parete cieca	NW	15	0.88	0.26	25	6.5
Parete finestrata	NW	15	7.88	1.25	25	283.0
Porta	NW	15		2.00	25	0
Parete interrato	N	20		0.22	25	0
Parete intercapedine	N	20		0.22	25	0
Parete controterra	=			0.22	10	0
Porta interna	=			2.00	10	0
Parete divisoria	=			0.40	10	0
Parete asola	=			0.00	10	0
Parete ascensore	=			0.22	10	0
Parete scala	=			0.22	10	0
Pav su terreno	=			0.21	10	0
Pav su esterno	oriz	20		0.29	25	0
Pav su loc no risc	oriz	20		0.292	20	0
Pav interpiano	=			0	10	0
Lucernaio	oriz			1.25	25	0
Copertura	=			0	25	0
Cop verso loc no risc	=			0.184	25	0
26						779.7

Conduction calculation for Thermal zone 116

On the column #1 is shown the typology of the closure, they can be: External opaque wall, window surface, internal wall, internal slab, slab against the ground, roof, skylight, etc.

On column #2 is stated the orientation of external surfaces, which determines the value of Column #3, the factor F_o that increases the conduction during winter condition, according to the provable humidity on them.

On column #4 it is located the component area in m^2 and on column #5 their conductivity, in W/m^2.

Finally on Column #6 is located the ΔT, which for external walls is $T_{interior} – T_{exterior}$ and for internal walls against a non-conditioned spaces is $(T_{interior} – T_{exterior})* b_{tr,u}$.

On subspace 116 there are two sides with possible thermal transfer through them, one facing west and the other south, since the internal divisions are facing other conditioned spaces, producing no heat transfer through them.

No matter this, since the geometry shape of the envelope is not regular but angular on the wall components, each side must me divided according to the corresponding orientation of the components.

West Facing Facade:

Two windows facing the north-west orientation, with 1.25m length and 3.15m height:

$$\dot{Q}_f = U * A * \Delta T * F_o = 1.25 \frac{W}{m^2 K} * \ 2(1.25m * 3.15m) * \ 25°K * 1.15 = 283W$$

There is the opaque surface facing the same orientation, located on top and below the mentioned windows, with 0.35m height:

$$\dot{Q}_f = U * A * \Delta T * F_o = 0.257 \frac{W}{m^2 K} * 2(1.25m * 0.35m). 25°K * 1.15 = 6.5W$$

The opaque surfaces between each of the window with 0.65m length facing the south-west orientation, can be summed up with the ones below and on top the South-façade windows, since both face the same orientation:

$$\dot{Q}_f = U * A * \Delta T * F_o$$

$$= 0.257 \frac{W}{m^2 K} * (2(0.65m * 3.5m) + 3(1.25m * 0.35m)) * 25°K * 1.05 = 39.5W$$

Also it is considered the lateral side of the columns facing flat south orientation:

$$\dot{Q}_f = U * A * \Delta T * F_o = 0.257 \frac{W}{m^2 K} * (0.6m * 3.5m). 25°K * 1.10 = 14.8W$$

South Facing Facade:

Three windows facing the south-west orientation with 1.25m x 3.15m:

$$\dot{Q}_f = U * A * \Delta T * F_o = 1.25 \frac{W}{m^2 K} * \ 3(1.25m * 3.15m) * \ 25°K * 1.05 = 387.6W$$

Opaque surfaces between each of the windows with 0.65m length and full height of the floor (3.5m):

$$\dot{Q}_f = U * A * \Delta T * F_o = 0.257 \frac{W}{m^2 K} * 3(0.65m * 3.5m). 25°K * 1.10 = 48.2W$$

On the previously equations:

- $0.257\frac{W}{m^2K}$ and $1.25\,\frac{W}{m^2K}$ are the Uvalues of the external wall and windows respectively.
- The values of ΔT,and the $F_o$are stated on ***Chapter 1.6: Parameters applied on the method.***

The total heat transfer by conduction of the several components of the Space 116 is summed up:

$$\dot{Q}_f\ Space\ 116 = 283W + 6.5W + 39.5W + 14.8W + 387.6W + 48.2W = 779.7W$$

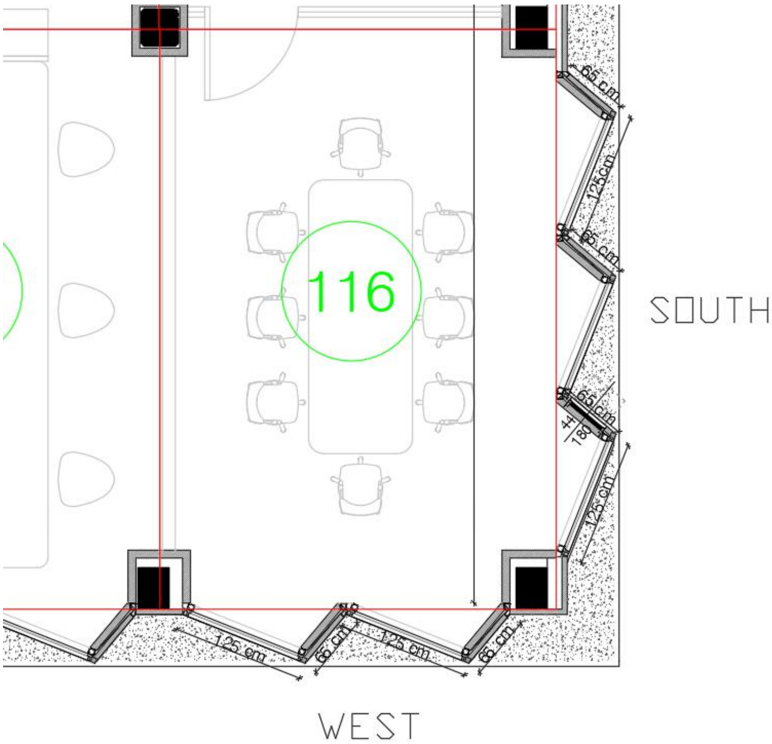
Having found the 779.7W of heat transfer on the Space 116, it is calculated in the same way the value of the other spaces of the entire building. Following the same procedure, there is a result of 59.015kW that are leaving the building by conduction during the winter condition.

This total energy transfer must be countered by the heating power provided from the thermal plant in order to maintain each zone on the required temperature conditions. Therefore, this sum of all the energy transfers by conduction multiplied by 1.2 (security factor) is equal to the value for the pre-dimensioning of the HVAC, which means 70.818kW of heating power needs to be provided by the plant during winter condition.

1.8. Peak cooling needs estimation for summer

The cooling plant pre-sizing process is similar to the heating previously seen, with the condition that now during summertime, the heat goes from outside to inside the thermal zones, so it needs to be extracted instead of provided by the plant. The internal gains and the effect of the sun irradiation on the external surfaces are also considered.

The same room 116 will be subjected to the cooling loads analysis. During summer, the heat flux goes from the exterior space with an air temperature of 32ºC (or from non-conditioned spaces) to the interior spaces with a conditioned thermal set point of 24ºC. (Temperatures for Milan's case and specific project setpoint).



We divide the calculation according to the typology of closure we have:

1.8.1.Opaque external closure (wall or roof):

We calculate the thermal heat transfer entering the opaque walls of room 116 by conduction at three different hours (9am, 12m and 4pm), following the next equation:

$$\Delta Teq = a + \Delta T_{es} + b * \frac{R_s}{R_m} * (\Delta T_{em} - \Delta T_{es})$$

With:

- ΔTeq as new ΔT fixed, to be considered in the calculation of heat transfer through opaque closures by conduction, in Celsius.

- a is a correction value, depends to the delta t between interior and outside, and the delta t over the 24h. From Tab 3.19 with $\Delta T24h$ = 12ºC and $\Delta T_{ext-int}$ = 8ºC, temperatures for this project, we have:

Tab. 3.19 - Correzioni delle differenze di temperatura equivalente (°C).

Temperatura esterna alle ore 15, per il mese considerato, meno temperatura interna (°C)	Escursione della temperatura esterna nelle 24 ore																	
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
16	–21,2	–21,7	–22,3	–22,8	–23,3	–23,8	–24,2	–24,7	–25,1	–25,6	–26,0	–26,5	–27,0	–27,4	–27,9	–28,8	–29,3	–29,8
12	–17,2	–17,7	–18,3	–18,8	–19,3	–19,8	–20,2	–20,7	–21,1	–21,6	–22,0	–22,5	–23,0	–23,4	–23,9	–24,8	–25,3	–25,8
8	–13,2	–13,7	–14,3	–14,8	–15,3	–15,8	–16,2	–16,7	–17,1	–17,6	–18,0	–18,5	–19,0	–19,4	–19,9	–20,8	–21,3	–21,8
4	–9,2	–9,7	–10,3	–10,8	–11,3	–11,8	–12,2	–12,7	–13,1	–13,6	–14,0	–14,5	–15,0	–15,4	–15,9	–16,8	–17,3	–17,8
0	–5,0	–5,5	–6,1	–6,6	–7,1	–7,6	–8,0	–8,5	–8,9	–9,4	–9,8	–10,3	–10,8	–11,2	–11,7	–12,6	–13,1	–13,6
+2	–3,1	–3,6	–4,2	–4,7	–5,2	–5,6	–6,1	–6,6	–7,0	–7,5	–7,9	–8,4	–8,9	–9,3	–9,8	–10,6	–11,1	–11,7
+4	–1,1	–1,6	–2,2	–2,7	–3,2	–3,6	–4,1	–4,6	–5,0	–5,5	–5,9	–6,4	–6,9	–7,3	–7,8	–8,6	–9,1	–9,7
+6	0,8	0,3	–0,3	–0,8	–1,3	–1,7	–2,2	–2,7	–3,1	–3,6	–4,0	–4,5	–5,0	–5,4	–5,9	–6,7	–7,2	–7,8
+8	2,8	2,3	1,7	1,2	0,7	0,3	0,0	–0,7	–1,1	–1,6	–2,0	–2,5	–3,0	–3,4	–3,9	–4,7	–5,2	–5,8
+10	4,7	4,2	3,6	3,1	2,6	2,2	1,7	1,2	0,8	0,3	–0,1	–0,6	–1,1	–1,5	–2,0	–2,8	–3,3	–3,9
+12	6,8	6,3	5,7	5,2	4,7	4,3	3,8	3,3	2,9	2,4	1,8	1,3	0,8	0,4	–0,1	–0,7	–1,2	–1,8
+14	8,8	8,3	7,7	7,2	6,7	6,3	5,8	5,3	4,9	4,4	3,8	3,3	2,8	2,4	1,9	1,3	0,8	0,2
+16	10,8	10,3	9,7	9,2	8,7	8,3	7,8	7,3	6,9	6,4	5,8	5,3	4,8	4,4	3,9	3,3	2,8	2,2
+18	12,8	12,3	11,7	11,2	10,7	10,3	9,8	9,3	8,9	8,4	7,8	7,3	6,8	6,4	5,9	5,3	4,8	4,2
+20	14,8	14,3	13,7	13,2	12,7	12,3	11,8	11,3	10,9	10,4	9,8	9,3	8,8	8,4	7,9	7,3	6,8	6,2
+22	16,9	16,4	15,8	15,3	14,8	14,4	13,9	13,4	13,0	12,5	11,9	11,4	10,9	10,5	10,0	9,4	8,9	8,3

$$\boldsymbol{a = -0.7}$$

- ΔT_{es} as equivalent temperature difference for the wall or roof in shadow, depends on the wall/roof mass, which for this case is 500kg/m^2. From *Tab. 3.17- Differenza di temperature equivalente per muri irradiati o in ombra – Manuale della Climatizzazione.*

Orientamento	Massa frontale *** (kg/m²)	Ora solare																							
		Mattino							Pomeriggio-Notte													Mattino				
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
N (in ombra)	100	–1,7	–1,7	–2,2	–1,7	–1,1	0,5	2,2	4,4	5,5	6,7	7,8	7,2	6,7	5,5	4,4	3,3	2,2	1,1	0,0	0	–0,5	–0,5	–1,1	–1,1
	300	–1,7	–1,7	–2,2	–1,7	–1,1	–0,5	0,0	1,7	3,3	4,4	5,5	6,1	6,7	6,7	6,7	5,5	4,4	3,3	2,2	1,1	0,5	0,0	–0,5	–1,1
	500	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,5	1,1	1,7	2,2	2,8	2,8	2,8	4,4	3,9	3,3	2,8	2,2	1,7	1,7	1,1	1,1	0,5
	700	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	1,1	1,7	2,2	2,8	3,3	3,9	4,4	3,9	3,3	2,2	1,7	1,1	1,1	0,5

$$\boldsymbol{\Delta T_{es}(9h \& 12h) = 0ºC \quad \Delta T_{es}(16h) = 2.2ºC}$$

- b as colour factor, (1 for dark, 0.78 for medium and 0.55 for light colour), unitless. On this project the opaque walls have medium color, which makes $\boldsymbol{b = 0.78}$

- R_m as maximum radiation at 40° Latitude on the month of July, in W/m^2. From *Tab. 3.22. Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice - Manuale della Climatizzazione.*

Tab. 3.22 - Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice* (W/m²).

Latitudine nord	Mese	Orientamento (latitudine nord)									Mese	Latitudine sud
		N**	NE	E	SE	S	SO	O	NO	Orizz.		
40°	Luglio e maggio	47	400	517	394	218	394	517	400	737	Nov. e gennaio	40°
	Agosto e aprile	34	321	511	460	321	460	511	321	675	Ottobre e febbraio	
	Settembre e marzo	28	183	470	510	441	510	470	183	577	Settembre e marzo	
	Ottobre e febbraio	22	109	384	514	511	514	384	109	406	Agosto e aprile	
	Nov. e gennaio	15	37	315	492	524	492	315	37	325	Luglio e maggio	
	Dicembre	15	31	271	467	520	467	271	31	268	Giugno	

$$\boldsymbol{R_m = 517\ W/m^2}$$

- R_s as maximum radiation for the surface orientation, on the month of analysis, at the building latitude. On space 116 the opaque walls are facing West, South-west, south-east, and north-west latitude with the building located in Milan at 45º30’ North Latitude. Therefore, the irradiation values are taken for 40º and 50º latitude from *Tab3.22* and interpolated to find the values at 45º30’.

Tab. 3.22 - Carichi massimi dovuti alla radiazione solare attraverso il vetro semplice* (W/m²).

Latitudine nord	Mese	Orientamento (latitudine nord)									Mese	Latitudine sud
		N**	NE	E	SE	S	SO	O	NO	Orizz.		
0°	Giugno	186	492	463	131	44	131	463	492	712	Dicembre	0°
	Luglio e maggio	151	482	479	164	44	164	479	482	734	Nov. e gennaio	
	Agosto e aprile	78	444	514	249	44	249	514	444	773	Ottobre e febbraio	
	Settembre e marzo	31	372	526	372	44	372	526	372	789	Settembre e marzo	
	Ottobre e febbraio	31	249	514	444	107	444	514	249	773	Agosto e aprile	
	Nov. e gennaio	31	164	479	482	211	482	479	164	734	Luglio e maggio	
	Dicembre	31	131	463	492	258	492	463	131	712	Giugno	
10°	Giugno	126	482	489	173	44	173	489	482	767	Dicembre	10°
	Luglio e maggio	94	467	498	208	44	208	498	467	778	Nov. e gennaio	
	Agosto e aprile	41	410	514	296	44	296	514	410	789	Ottobre e febbraio	
	Settembre e marzo	31	325	517	400	87	400	517	325	778	Settembre e marzo	
	Ottobre e febbraio	31	208	489	470	230	470	488	208	725	Agosto e aprile	
	Nov. e gennaio	28	116	450	507	334	318	450	116	662	Luglio e maggio	
	Dicembre	28	87	432	514	377	514	432	87	636	Giugno	
20°	Giugno	81	485	504	230	44	230	504	485	789	Dicembre	20°
	Luglio e maggio	59	435	514	268	44	268	514	435	791	Nov. e gennaio	
	Agosto e aprile	34	372	520	356	81	356	520	372	778	Ottobre e febbraio	
	Settembre e marzo	31	273	514	441	205	441	514	273	734	Settembre e marzo	
	Ottobre e febbraio	28	164	463	504	350	504	463	164	656	Agosto e aprile	
	Nov. e gennaio	24	81	404	517	444	517	404	81	568	Luglio e maggio	
	Dicembre	24	56	382	526	470	526	382	56	536	Giugno	
30°	Giugno	63	439	507	284	66	284	507	439	789	Dicembre	30°
	Luglio e maggio	50	413	517	315	94	315	517	413	776	Nov. e gennaio	
	Agosto e aprile	34	340	520	406	198	406	520	340	741	Ottobre e febbraio	
	Settembre e marzo	28	284	498	479	330	479	498	284	668	Settembre e marzo	
	Ottobre e febbraio	24	122	426	514	457	514	426	122	564	Agosto e aprile	
	Nov. e gennaio	22	50	365	511	502	511	365	50	457	Luglio e maggio	
	Dicembre	19	37	330	511	514	511	330	37	413	Giugno	
40°	Giugno	54	419	511	350	170	350	511	419	747	Dicembre	40°
	Luglio e maggio	47	400	517	394	218	394	517	400	737	Nov. e gennaio	
	Agosto e aprile	34	321	511	460	321	460	511	321	675	Ottobre e febbraio	
	Settembre e marzo	28	183	470	510	441	510	470	183	577	Settembre e marzo	
	Ottobre e febbraio	22	109	384	514	511	514	384	109	406	Agosto e aprile	
	Nov. e gennaio	15	37	315	492	524	492	315	37	325	Luglio e maggio	
	Dicembre	15	31	271	467	520	467	271	31	268	Giugno	
50°	Giugno	50	397	517	426	293	426	517	397	694	Dicembre	50°
	Luglio e maggio	44	369	514	450	334	450	514	369	666	Nov. e gennaio	
	Agosto e aprile	34	296	498	495	435	495	498	296	583	Ottobre e febbraio	
	Settembre e marzo	24	183	435	514	498	514	435	183	467	Settembre e marzo	
	Ottobre e febbraio	15	91	330	495	526	495	330	91	296	Agosto e aprile	
	Nov. e gennaio	12	28	201	400	482	400	201	28	166	Luglio e maggio	
	Dicembre	9	22	148	365	444	365	148	22	126	Giugno	

SE orientation & SW orientation: **423W/m².**

West orientation: **516 W/m².**

North West Orientation: **385 W/m²**.

- ΔT_{em} as equivalent temperature difference for the wall or roof in sun exposition, under the parameters explained on C*hapter 1.2.* They are taken at three different hours: 9h, 12h and 16h for the specific wall orientation from Tab 3.17 in Manuale della Climatizzazione.

Tab. 3.17 - Differenza di temperatura equivalente (°C). Muri irradiati o in ombra*. Valida per muri di colore scuro, temperatura esterna 35 °C, temperatura interna 27 °C, escursione della temperatura esterna nelle 24 ore pari a 11 °C, mese di luglio e 40° di latitudine nord.**

Orientamento	Massa frontale *** (kg/m²)	Ora solare																								
		Mattino							Pomeriggio-Notte												Mattino				
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
NE	100	2,8	8,3	12,2	12,8	13,3	10,6	7,8	7,2	6,7	7,2	7,8	7,8	7,8	6,7	5,5	4,4	3,3	2,2	1,1	0,0	–1,1	–1,7	–2,2	–1,1
	300	–0,5	–1,1	–1,1	2,8	13,3	12,2	11,1	8,3	5,5	6,1	6,7	7,2	7,8	7,2	6,7	6,1	5,5	4,4	3,3	2,2	1,1	0,5	0,0	–0,5
	500	2,2	1,7	2,2	2,2	2,2	5,5	8,9	8,3	7,8	6,7	5,5	6,1	6,7	6,7	6,7	6,1	5,5	5,0	4,4	3,9	3,3	3,3	2,8	2,8
	700	2,8	2,8	3,3	3,3	3,3	3,3	3,3	5,5	7,8	8,9	7,8	6,7	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,0	5,0	4,4	3,9	3,9
E	100	0,5	9,4	16,7	18,3	20,0	19,4	17,8	11,1	6,7	7,2	7,8	7,8	7,8	6,7	5,5	4,4	3,3	2,2	1,1	0,0	–0,5	–1,1	–1,7	–1,7
	300	–0,5	–0,5	0,0	11,7	16,7	17,2	17,2	10,6	7,8	7,2	6,7	7,2	7,8	7,2	6,7	6,1	5,5	4,4	2,8	2,2	1,7	0,5	0,5	0,0
	500	2,8	2,8	3,3	4,4	7,8	11,1	13,3	13,9	13,3	11,1	10,0	8,9	7,8	7,8	7,8	7,2	6,7	6,1	5,5	5,0	4,4	3,9	3,9	3,3
	700	6,1	5,5	5,5	5,0	4,4	5,0	5,5	8,3	10,0	10,6	10,0	9,4	8,9	7,8	6,7	7,2	7,8	7,8	7,8	7,2	7,2	6,7	6,7	6,7
SE	100	5,5	3,3	7,2	10,6	14,4	15,0	15,6	14,4	13,3	10,6	8,9	8,3	7,8	6,7	5,5	4,4	3,3	2,2	1,1	0,0	–0,5	–0,5	–1,1	–1,1
	300	0,5	0,5	0,0	7,2	11,1	13,3	15,6	14,4	13,9	11,7	10,0	8,3	7,8	7,2	6,7	6,1	5,5	4,4	3,3	2,8	2,2	1,7	1,7	1,1
	500	3,9	3,9	3,3	3,3	3,3	6,1	8,9	9,4	10,0	10,6	10,0	9,4	7,8	7,2	6,7	6,1	5,5	5,5	5,5	5,0	5,0	4,4	4,4	3,9
	700	5,0	4,4	4,4	4,4	4,4	3,9	3,3	6,1	7,8	8,3	8,9	10,0	8,9	8,3	7,8	7,2	6,7	6,7	6,7	6,1	6,1	5,5	5,5	5,0
S	100	–0,5	–1,1	–2,2	0,5	2,2	7,8	12,2	15,0	16,7	15,6	14,4	11,1	8,9	6,7	5,5	3,9	3,3	1,7	1,1	0,5	0,5	0,0	0,0	–0,5
	300	–0,5	–1,7	–2,2	–1,7	–1,1	3,9	6,7	11,1	13,3	13,9	14,4	12,8	11,1	8,3	6,7	5,5	4,4	3,3	2,2	1,1	0,5	0,5	0,0	–0,5
	500	2,2	2,2	1,1	1,1	1,1	1,7	2,2	4,4	6,7	8,3	8,9	10,0	10,0	8,3	7,8	6,1	5,5	5,0	4,4	4,4	3,9	3,3	3,3	2,8
	700	3,9	3,3	3,3	2,8	2,2	2,2	2,2	2,2	2,2	3,9	5,5	7,2	7,8	8,3	8,9	8,9	7,8	6,7	5,5	5,5	5,0	5,0	4,4	3,9
SO	100	–1,1	–2,2	–2,2	–1,1	0,0	2,2	3,3	10,6	14,4	18,9	22,2	22,8	23,3	16,7	13,3	6,7	3,3	2,2	1,1	0,5	0,5	0,0	–0,5	–0,5
	300	1,1	0,5	0,0	0,0	0,0	0,5	1,1	4,4	6,7	13,3	17,8	19,4	20,0	19,4	18,9	11,1	5,5	3,9	3,3	2,8	2,2	2,2	1,7	1,7
	500	3,9	2,8	3,3	2,8	2,2	2,8	3,3	3,9	4,4	6,7	7,8	10,6	12,2	12,8	13,3	12,8	12,2	8,3	5,5	5,5	5,0	5,0	4,4	3,9
	700	4,4	4,4	4,4	4,4	4,4	3,9	3,3	3,3	3,3	3,9	4,4	5,0	5,5	8,3	10,0	10,6	11,1	7,2	4,4	4,4	4,4	4,4	4,4	4,4
O	100	–1,1	–1,7	–2,2	–1,1	0,0	1,7	3,3	7,8	11,1	17,8	22,2	25,0	26,7	18,9	12,2	7,8	4,4	2,8	1,1	0,5	0,0	0,0	–0,5	–0,5
	300	1,1	0,5	0,0	0,0	0,0	1,1	2,2	3,9	5,5	10,6	14,4	18,9	22,2	22,8	20,0	15,6	8,9	5,5	3,3	2,8	2,2	1,7	1,7	1,1
	500	3,9	3,9	3,3	3,3	3,3	3,3	3,3	3,9	4,4	5,5	6,7	9,4	11,1	13,9	15,6	15,0	14,4	10,6	7,8	6,7	6,1	5,5	5,0	4,4
	700	6,7	6,1	5,5	5,0	4,4	4,4	4,4	5,0	5,5	5,5	5,5	6,1	6,7	7,8	8,9	11,7	12,2	12,8	12,2	11,1	10,0	8,9	8,3	7,2
NO	100	–1,7	–2,2	–2,2	–1,1	0,0	1,7	3,3	5,5	6,7	10,6	13,3	18,3	22,2	20,6	18,9	10,0	3,3	2,2	1,1	0	–0,5	–0,5	–1,1	–1,1
	300	–1,1	–1,7	–2,2	–1,7	–1,1	0,0	1,1	3,3	4,4	5,5	6,7	11,7	16,7	17,2	17,8	11,7	6,7	4,4	3,3	2,2	1,7	0,5	0,0	–0,5
	500	2,8	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,8	3,3	5,0	6,7	9,4	11,1	11,7	12,2	7,8	4,4	3,9	3,9	3,3	3,3	2,8
	700	4,4	3,9	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,9	4,4	5,0	5,5	7,8	10,0	10,6	11,1	8,9	7,2	6,1	5,5	5,0

SE orientation: **9h =3.3ºC**; **12h= 8.9ºC** ; **16h= 10ºC.**

SW orientation: **9h =2.8ºC**; **12h= 3.3ºC** ; **16h= 7.8ºC.**

West orientation: **9h =3.3ºC**; **12h= 3.3ºC** ; **16h= 6.7ºC.**

Northwest orientation: **9h =2.2ºC**; **12h= 2.2ºC** ; **16h= 3.3ºC.**

Implementing all the previous parameters on Temperature equivalent equation for Southeast orientation:

$$\Delta Teq = a + \Delta T_{es} + b * \frac{R_s}{R_m} * (\Delta T_{em} - \Delta T_{es})$$

$$\Delta Teq(9h) = -0.7°C + 0°C + 0.78 * \frac{423\,\frac{W}{m2}}{517\,\frac{W}{m2}} * (3.3°C - 0°C) \; = 1.4°C$$

$$\Delta Teq(12h) = -0.7°C + 0°C + 0.78 * \frac{423\,\frac{W}{m2}}{517\,\frac{W}{m2}} * (8.9°C - 0°C) \; = 5°C$$

$$\Delta Teq(16h) = -0.7°C + 2.2°C + 0.78 * \frac{423\,\frac{W}{m2}}{517\,\frac{W}{m2}} * (10°C - 2.2°C) \; = 6.5°C$$

For Southwest Orientation:

$$\Delta Teq(9h) = -0.7°C + 0°C + 0.78 * \frac{423\frac{W}{m2}}{517\frac{W}{m2}} * (2.8°C - 0°C) \ = 1.1°C$$

$$\Delta Teq(12h) = -0.7°C + 0°C + 0.78 * \frac{423\frac{W}{m2}}{517\frac{W}{m2}} * (3.3°C - 0°C) \ = 1.4°C$$

$$\Delta Teq(16h) = -0.7°C + 2.2°C + 0.78 * \frac{423\frac{W}{m2}}{517\frac{W}{m2}} * (7.8°C - 2.2°C) \ = 5.1°C$$

For West Orientation:

$$\Delta Teq(9h) = -0.7°C + 0°C + 0.78 * \frac{516\frac{W}{m2}}{517\frac{W}{m2}} * (3.3°C - 0°C) \ = 1.9°C$$

$$\Delta Teq(12h) = -0.7°C + 0°C + 0.78 * \frac{516\frac{W}{m2}}{517\frac{W}{m2}} * (3.3°C - 0°C) \ = 1.9°C$$

$$\Delta Teq(16h) = -0.7°C + 2.2°C + 0.78 * \frac{516\frac{W}{m2}}{517\frac{W}{m2}} * (6.7°C - 2.2°C) \ = 5°C$$

For Northwest Orientation:

$$\Delta Teq(9h) = -0.7°C + 0°C + 0.78 * \frac{385\frac{W}{m2}}{517\frac{W}{m2}} * (2.2°C - 0°C) \ = 0.6°C$$

$$\Delta Teq(12h) = -0.7°C + 0°C + 0.78 * \frac{385\frac{W}{m2}}{517\frac{W}{m2}} * (2.2°C - 0°C) \ = 0.6°C$$

$$\Delta Teq(16h) = -0.7°C + 2.2°C + 0.78 * \frac{385\frac{W}{m2}}{517\frac{W}{m2}} * (3.3°C - 2.2°C) \ = 2.1°C$$

Previously parameters for all the different orientations are located on the table below, making it easier the calculation of ΔTeq using Excel as a tool.

MEDIO (verde, grigio) - 500kg											
	h 9	h 12	h 16	h 9	h 12	h 16	h 9	h 12	h 16	per	Rs
esp.	ΔT eq. Corretto			ΔT eq. Sole			ΔT eq. Ombra			ΔT	W/mq
N	**-0.7**	**-0.7**	**1.5**	0	0	2.2	0	0	2.2	-0.7	71
E	**2.7**	**9.7**	**7.6**	4.4	13.3	10	0	0	2.2	-0.7	516
S	**-0.2**	**0.2**	**4.3**	1.1	2.2	8.9	0	0	2.2	-0.7	276
W	**1.9**	**1.9**	**5.0**	3.3	3.3	6.7	0	0	2.2	-0.7	516
NE	**0.6**	**4.5**	**3.4**	2.2	8.9	5.5	0	0	2.2	-0.7	385
SE	**1.4**	**5.0**	**6.5**	3.3	8.9	10	0	0	2.2	-0.7	423
SW	**1.1**	**1.4**	**5.1**	2.8	3.3	7.8	0	0	2.2	-0.7	423
NW	**0.6**	**0.6**	**2.1**	2.2	2.2	3.3	0	0	2.2	-0.7	385

Table for ΔTeq calculation, values for a 500kg wall of medium colour compiled by Lombardini 22 taken the parameters from Manuale della climatizzazione.

The last step is to multiply each different ΔTeq by the area of each surface and its Uvalue, in order to find the heat transfer passing through the opaque envelope, considering now after the procedure above, the effect of the solar radiation.

$$\dot{Q} = U * A * \Delta Teq$$

Southeast facing walls:

$$\dot{Q}(9h) = 0.257 \frac{W}{m^2K} * 3(0.65m * 3.5m) * 1.4°C = 2.47W$$
$$\dot{Q}(12h) = 0.257 \frac{W}{m^2K} * 3(0.65m * 3.5m) * 5°C = 8.73W$$
$$\dot{Q}(16h) = 0.257 \frac{W}{m^2K} * 3(0.65m * 3.5m) * 6.5°C = 11.44W$$

Southwest facing walls:

$$\dot{Q}(9h) = 0.257 \frac{W}{m^2K} * (2(0.65m * 3.5m) + 3(1.25m * 0.35m)) * 1.1°C = 1.64W$$
$$\dot{Q}(12h) = 0.257 \frac{W}{m^2K} * (2(0.65m * 3.5m) + 3(1.25m * 0.35m)) * 1.4°C = 2.12W$$
$$\dot{Q}(16h) = 0.257 \frac{W}{m^2K} * (2(0.65m * 3.5m) + 3(1.25m * 0.35m)) * 5.1°C = 7.69W$$

West facing walls:

$$\dot{Q}(9h\&12h) = 0.257 \frac{W}{m^2K} * 2(0.3m * 3.5m) * 1.9°C = 1.01W$$
$$\dot{Q}(16h) = 0.257 \frac{W}{m^2K} * 2(0.3m * 3.5m) * 5°C = 2.72W$$

Northwest facing walls:

$$\dot{Q}(9h\&12h) = 0.257 \frac{W}{m^2K} * 2(1.25m * 0.35m) * 0.6°C = 0.13W$$
$$\dot{Q}(16h) = 0.257 \frac{W}{m^2K} * 2(1.25m * 0.35m) * 2.1°C = 0.48W$$

1.8.2.Internal walling:

For internal/partition walling is used the normal equation of conduction since they are not subjected of solar irradiation.

$$\dot{Q} = U * A * \Delta T$$

Initial ΔT among internal walls exist between conditioned and non-conditioned spaces and it is calculated with the "Fattore di correzione" showed on *Chapter 1.6*.

In summer it is decreased by 6, 3 or 0 ºC degrees according to the time of analysis, and should be greater than 0 after the subtraction, otherwise it is not considered in the conduction calculation.

$$\Delta T\ (9h) = \Delta T\ - 6°C$$

$$\Delta T\ (12h) = \Delta T\ - 3°C$$

$$\Delta T\ (16h) = \Delta T$$

For an internal wall of 1m length by 3.5m height (U=0.4$\frac{W}{m^2K}$), located between an interior conditioned space X with a set point temperature in summer of 24$°C$ and a non-conditioned space with one external wall, during summer condition at 32ºC of outside air temperature, the heat transfer is:

$$\Delta T = (T_{ext} - T_{int}) * b_u = \ (32°C - 24°C) * 0.4 = 3.2°C$$

$$\dot{Q}(9h) = U.A.\Delta T(9h) = \ 0.40\frac{W}{m^2K} * (1 * 3.5)m^2 * (3.2 - 6)°C = \emptyset$$

It is not considered since its less than 0.

$$\dot{Q}(12h) = U.A.\Delta T(12h) = 0.40\frac{W}{m^2K}\ * (1 * 3.5)m^2 * (3.2 - 3)°C = 0.28W$$

$$\dot{Q}(16h) = U.A.\Delta T(16h) = 0.40\frac{W}{m^2K}\ * (1 * 3.5)m^2 * (3.2 - 0)°C = 4.5W$$

*On room 116 there are no internal walls facing not conditioned spaces, that is the reason why a generic example was implemented**

1.8.3.Transparent external surface or window:

On this type of envelope there is conduction and irradiance passing through the surface, both heating the internal space.

The conduction is calculated as for internal walling, decreasing the ΔT on 6, 3 and 0 celsius degrees according to the hour, multiplied by the Uvalue of the glass and its area. While the entering irradiance is calculated depending on the frame material, presence or not of solar screen and/or blinds, accumulation of heat depending on the hour, and most importantly, the average solar irradiance on site, specific of the window's orientation.

On thermal zone 116 example, there are two windows facing Northwest orientation and three facing Southwest orientation, all with 1.25m length by 3.15m height.
We proceed to calculate the heat transfer through them, due to the interior ($24°C$) and exterior ($32°C$) temperature difference and the sun irradiation.

First we calculate the thermal conduction for the three different hours of analysis:

Southwest orientation:

$$\dot{Q}(9h) = U * A * \Delta T(9h) = 1.25\frac{W}{m^2K} * 3(1.25m * 3.15m) * (8-6)°C = 29.53W$$

$$\dot{Q}(12h) = U * A * \Delta T(12h) = 1.25\frac{W}{m^2K} * 3(1.25m * 3.15m) * (8-3)°C = 73.83W$$

$$\dot{Q}(16h) = U * A * \Delta T(16h) = 1.25\frac{W}{m^2K} * 3(1.25m * 3.15m) * (8-0)°C = 118.13W$$

Northwest orientation:

$$\dot{Q}(9h) = U * A * \Delta T(9h) = 1.25\frac{W}{m^2K} * 2(1.25m * 3.15m) * (8-6)°C = 19.69W$$

$$\dot{Q}(12h) = U * A * \Delta T(12h) = 1.25\frac{W}{m^2K} * 2(1.25m * 3.15m) * (8-3)°C = 49.22W$$

$$\dot{Q}(16h) = U * A * \Delta T(16h) = 1.25\frac{W}{m^2K} * 2(1.25m * 3.15m) * (8-0)°C = 78.75W$$

Then we proceed to calculate the irradiance passing trough the windows. For this project was selected a double glass window with a mass of 500kg/m^2, low-e coating on the external glass, and an internal venetian blind for shading. The irradiance "E" its calculated following the next formula:

$$\mathrm{E} = I_{max} * A_{cc} * C_f$$

With:

- I_{max} as the maximum irradiation on the window orientation for the project's latitude. It is taken for the month of analysis (July) and for each different window orientation (Northwest and Southwest) from *Tab 3.21 of Manuale della Climatizzazione.*

  Since the Building is located in Milan at 45º30' North Latitude, the irradiation values are taken for 40º and 50º latitude, and then interpolated, this for each specific hour of analysis.

Tab. 3.21 - *(Continua dalla pagina precedente)*.

40° Latitudine 40°

40° Latitudine nord		Ora solare													40° Latitudine sud	
Periodo	Orientamento	6	7	8	9	10	11	12	13	14	15	16	17	18	Orientamento	Periodo
21 giugno	N	101	63	38	41	44	44	44	44	44	41	38	63	**101**	S	22 dicembre
	N E	372	419	353	230	95	44	44	44	44	41	38	32	19	S E	
	E	397	508	**511**	448	300	139	44	44	44	41	38	32	19	E	
	S E	161	278	344	**350**	312	224	107	44	44	41	38	32	19	N E	
	S	19	32	38	60	110	139	**170**	139	110	60	38	32	19	N	
	S O	19	32	38	41	44	44	107	224	312	**350**	344	278	161	N O	
	O	19	32	38	41	44	44	44	139	300	448	511	508	397	O	
	N O	19	32	38	41	44	44	44	44	95	230	353	419	372	S O	
	Orizzontale	98	259	423	565	662	732	747	732	662	565	423	259	98	Orizzontale	
23 luglio e 21 maggio	N	**76**	44	38	41	44	44	44	44	44	41	38	44	**76**	S	21 gennaio e 21 novembre
	N E	334	**401**	331	208	82	44	44	44	44	41	38	32	16	S E	
	E	372	508	517	454	309	136	44	44	44	41	38	32	16	E	
	S E	170	303	375	**394**	347	259	132	47	44	41	38	32	16	N E	
	S	16	32	41	82	139	199	**218**	199	139	82	41	32	16	N	
	S O	16	32	38	41	44	47	132	259	347	**394**	375	303	170	N O	
	O	16	32	38	41	44	44	44	136	309	454	517	508	372	O	
	N O	16	32	38	41	44	44	44	44	82	208	331	**401**	334	S O	
	Orizzontale	76	230	397	539	640	710	**735**	710	640	539	397	230	76	Orizzontale	
24 agosto e 20 aprile	N	22	25	35	41	44	44	**44**	44	44	41	35	25	22	S	20 febbraio e 23 ottobre
	N E	214	**322**	259	145	50	44	44	44	44	41	35	25	9	S E	
	E	265	464	**511**	457	319	142	44	44	44	41	35	25	9	E	
	S E	151	331	435	**460**	438	337	208	79	44	41	35	25	9	N E	
	S	9	25	76	161	281	306	**322**	306	281	161	76	25	9	N	
	S O	9	25	35	41	44	79	208	337	438	**460**	435	331	151	N O	
	O	9	25	35	41	44	44	44	142	319	457	**511**	464	265	O	
	N O	9	25	35	41	44	44	44	44	50	145	259	**322**	214	S O	
	Orizzontale	28	148	315	473	583	647	**675**	647	583	473	315	148	28	Orizzontale	

Tab. 3.21 - *(Continua dalla pagina precedente)*.

50° Latitudine 50°

50° Latitudine nord		Ora solare													50° Latitudine sud	
Periodo	Orientamento	6	7	8	9	10	11	12	13	14	15	16	17	18	Orientamento	Periodo
	N	**91**	38	38	41	44	44	44	44	44	41	38	38	**91**	S	22 dicembre
	N E	397	394	296	158	50	44	44	44	44	41	38	32	25	S E	
	E	438	517	511	429	296	129	44	44	44	41	38	32	25	E	
S E	202	322	397	**426**	391	309	192	73	44	41	38	32	25	N E		
21 giugno	S	25	32	50	123	214	274	**293**	274	214	123	50	32	25	N	
	S O	25	32	38	41	44	73	192	309	391	**426**	397	322	202	N O	
	O	25	32	38	41	44	44	44	129	296	429	511	517	438	O	
	N O	25	32	38	41	44	44	44	44	50	158	296	394	397	S O	
	Orizzontale	139	271	419	546	621	675	694	675	621	546	419	271	139	Orizzontale	
23 luglio e 21 maggio	N	**66**	35	38	41	44	44	44	44	44	41	38	35	66	S	21 gennaio e 21 novembre
	N E	360	**369**	274	139	47	44	44	44	44	41	38	32	19	S E	
	E	413	508	**514**	445	303	136	44	44	44	41	38	32	19	E	
	S E	205	337	423	**451**	429	344	221	82	44	41	38	32	19	N E	
	S	19	32	66	158	252	309	**334**	309	252	158	66	32	19	N	
	S O	19	32	38	41	44	82	221	344	429	451	423	337	205	N O	
	O	19	32	38	41	44	44	44	136	303	445	**514**	508	413	O	
	N O	19	32	38	41	44	44	44	44	47	139	274	**369**	360	S O	
	Orizzontale	104	237	375	501	593	647	**665**	647	593	501	375	237	104	Orizzontale	
24 agosto e 20 aprile	N	25	25	32	38	41	44	**44**	44	41	38	32	25	25	S	20 febbraio e 23 ottobre
	N E	240	**296**	221	98	41	44	44	44	41	38	32	25	13	S E	
	E	296	457	**498**	445	309	142	44	44	41	38	32	25	13	E	
	S E	167	350	454	**495**	483	416	281	126	41	38	32	25	13	N E	
	S	13	28	114	230	331	410	**435**	410	331	230	114	28	13	N	
	S O	13	25	32	38	41	126	281	416	483	**495**	454	350	167	N O	
	O	13	25	32	38	41	44	44	142	309	445	**498**	457	296	O	
	N O	13	25	32	38	41	44	44	44	41	98	221	**296**	240	S O	
	Orizzontale	41	145	281	413	505	565	**583**	565	505	413	281	145	41	Orizzontale	

Southwest orientation: **9h =41W/m²; 12h= 181 W/m²; 16h= 401 W/m².**

Northwest orientation: **9h =41 W/m²; 12h= 44 W/m²; 16h= 300 W/m².**

- A_{cc} as accumulation Coefficient, which defines the amount of heat that remains inside the space over time, depends on the location of the screen/coating (internal or external) and the number of conditioned hours per day for the interior thermal space. For this specific project it is used a 500kg/m² window and a number of conditioned hours per day of 12, therefore we use the *Tab.3.28 from Manuale della Climatizzazione* to get the A_{cc} parameters.

Tab. 3.28 - Coefficienti d'accumulo dei carichi termici dovuti alla radiazione solare attraverso i vetri (12 ore di funzionamento a temperatura interna costante +).

Orientamento (latitudine nord)	Massa efficace dell'ambiente (x) (kg/m²)	Schermi interni*												Senza schermi o con schermi esterni++												Orientamento (latitudine sud)
		Ora solare																								
		Mattino							Pomeriggio					Mattino							Pomeriggio					
		6	7	8	9	10	11	12	13	14	15	16	17	6	7	8	9	10	11	12	13	14	15	16	17	
	750 e più	0,59	0,67	0,62	0,49	0,33	0,27	0,25	0,24	0,22	0,21	0,20	0,17	0,34	0,42	0,47	0,45	0,42	0,39	0,36	0,33	0,30	0,29	0,26	0,25	
NE	500	0,59	0,68	0,64	0,52	0,35	0,29	0,24	0,23	0,20	0,19	0,17	0,15	0,35	0,45	0,50	0,49	0,45	0,42	0,34	0,30	0,27	0,26	0,23	0,20	SE
	150	0,62	0,80	0,75	0,60	0,37	0,25	0,19	0,17	0,15	0,13	0,12	0,11	0,04	0,62	0,69	0,64	0,48	0,34	0,27	0,22	0,18	0,16	0,14	0,12	
	750 e più	0,51	0,66	0,71	0,67	0,57	0,40	0,29	0,26	0,25	0,23	0,21	0,19	0,36	0,44	0,50	0,53	0,53	0,50	0,44	0,39	0,36	0,34	0,30	0,28	
E	500	0,52	0,67	0,73	0,70	0,58	0,40	0,29	0,26	0,24	0,21	0,19	0,16	0,34	0,44	0,54	0,58	0,57	0,51	0,44	0,39	0,34	0,31	0,28	0,24	E
	150	0,53	0,74	0,82	0,81	0,65	0,43	0,25	0,19	0,16	0,14	0,11	0,09	0,36	0,56	0,71	0,76	0,70	0,54	0,39	0,28	0,23	0,18	0,15	0,12	
	750 e più	0,20	0,42	0,59	0,70	0,74	0,71	0,61	0,48	0,33	0,30	0,26	0,24	0,34	0,37	0,43	0,50	0,54	0,58	0,57	0,55	0,50	0,45	0,41	0,37	
SE	500	0,18	0,40	0,57	0,70	0,75	0,72	0,63	0,49	0,34	0,28	0,25	0,21	0,29	0,33	0,41	0,51	0,58	0,61	0,61	0,56	0,49	0,44	0,37	0,33	NE
	150	0,09	0,35	0,61	0,78	0,86	0,82	0,69	0,50	0,30	0,20	0,17	0,13	0,14	0,27	0,47	0,64	0,75	0,79	0,73	0,61	0,45	0,32	0,23	0,18	
	750 e più	0,28	0,25	0,40	0,53	0,64	0,72	0,77	0,77	0,73	0,67	0,49	0,31	0,47	0,43	0,42	0,46	0,51	0,56	0,61	0,65	0,66	0,65	0,61	0,54	
S	500	0,26	0,22	0,38	0,51	0,64	0,73	0,79	0,79	0,77	0,65	0,51	0,31	0,44	0,37	0,39	0,43	0,50	0,57	0,64	0,68	0,70	0,68	0,63	0,53	N
	150	0,21	0,29	0,48	0,67	0,79	0,88	0,89	0,83	0,56	0,50	0,24	0,16	0,28	0,19	0,25	0,38	0,54	0,68	0,78	0,84	0,82	0,76	0,61	0,42	
	750 e più	0,31	0,27	0,27	0,26	0,25	0,27	0,50	0,63	0,72	0,74	0,69	0,54	0,51	0,44	0,40	0,37	0,34	0,36	0,41	0,47	0,54	0,57	0,60	0,58	
SO	500	0,33	0,28	0,25	0,23	0,23	0,35	0,50	0,64	0,74	0,77	0,70	0,55	0,53	0,44	0,37	0,35	0,31	0,33	0,39	0,46	0,50	0,62	0,64	0,60	NO
	150	0,29	0,21	0,18	0,15	0,14	0,27	0,50	0,69	0,82	0,87	0,79	0,60	0,48	0,32	0,25	0,20	0,17	0,19	0,39	0,56	0,70	0,80	0,79	0,69	
	750 e più	0,63	0,31	0,28	0,27	0,25	0,24	0,22	0,29	0,46	0,61	0,71	0,72	0,56	0,49	0,44	0,39	0,36	0,33	0,31	0,31	0,35	0,42	0,49	0,54	
O	500	0,67	0,33	0,28	0,26	0,24	0,22	0,20	0,28	0,44	0,61	0,72	0,73	0,60	0,52	0,44	0,39	0,34	0,31	0,29	0,28	0,33	0,43	0,51	0,57	O
	150	0,77	0,34	0,25	0,20	0,17	0,14	0,13	0,22	0,44	0,67	0,82	0,85	0,77	0,56	0,38	0,28	0,22	0,18	0,16	0,19	0,33	0,52	0,69	0,77	
	750 e più	0,68	0,28	0,27	0,25	0,23	0,22	0,20	0,19	0,24	0,41	0,56	0,67	0,49	0,44	0,39	0,36	0,33	0,30	0,28	0,26	0,26	0,30	0,37	0,44	
NO	500	0,71	0,31	0,27	0,24	0,22	0,21	0,19	0,18	0,23	0,40	0,58	0,70	0,54	0,49	0,41	0,35	0,31	0,28	0,25	0,23	0,24	0,30	0,39	0,48	SO
	150	0,82	0,33	0,25	0,20	0,18	0,15	0,14	0,13	0,19	0,41	0,64	0,80	0,75	0,53	0,36	0,28	0,24	0,19	0,17	0,15	0,17	0,30	0,50	0,66	
N	750 e più	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,75	0,75	0,79	0,83	0,84	0,86	0,88	0,88	0,91	0,92	0,93	0,93	S
e in	500	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,98	0,81	0,84	0,86	0,89	0,91	0,93	0,93	0,94	0,94	0,95	0,95	0,95	e in
ombra	150	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	ombra

Due to the thermal properties of the window, we could consider it as it had an internal screen. The A_{cc} values for each specific orientation are:

A_{cc} for Southwest orientation: **9h =0.23**; **12h= 0.50**; **16h= 0.70.**

A_{cc} for Northwest orientation: **9h =0.24**; **12h= 0.19**; **16h= 0.58.**

- C_f as Correction Factor, which modifies the irradiance passing through the surface depending on the widow and frame typology, screen/coating or blind presence and climate conditions of the site. Follows the next equation:

$$C_f = F_{shad+screen} * F_{fog} * F_{frame} * F_{dew-point} * F_{altitude}$$

  - $F_{shading+screen}$ as Shading+Screen Factor. Goes from 1 to 0.1 and it is taken from *Tab.3.23 from Manuale della Climatizzazione*.

    The value is found on the table considering on the rows the number of glass layers, their thickness, colour, and the absorption coefficient of the external one and on the columns the type of shading we have and its specific colour.

    On this project we have a double glass window, with low-e coating on the external glass (which is considered as *absorbent 0.48/0.56*), and an internal venetian *white* blind for shading. Therefore the value **0.36** is taken.

Tab. 3.23 - Coefficienti correttivi di riduzione per i vetri con o senza schermi*.

Tipo di vetro	Senza schermo	Tende alla veneziana interne* Lamelle a 45° orizzontali o verticali o schermi in tela			Tende alla veneziana esterne Lamelle a 45° orizzontali		Schermo esterno Lamelle a 17° + orizzontali		Schermo in tela esterno Circolazione d'aria in alto e sui lati #	
		Colore chiaro	Colore medio	Colore scuro	Colore chiaro	Esterno chiaro Int. scuro	Colore medio**	Colore scuro^x	Colore chiaro	Colore medio o scuro
Vetro semplice comune	1,00	0,56	0,65	0,75	0,15	0,13	0,22	0,15	0,20	0,25
Vetro semplice 6 mm	0,94	0,56	0,65	0,74	0,14	0,12	0,21	0,14	0,19	0,24
Vetro assorbente ++										
Coeff. d'assorbimento 0,40÷0,48	0,80	0,56	0,62	0,72	0,12	0,11	0,18	0,12	0,16	0,20
Coeff. d'assorbimento 0,49÷0,56	0,73	0,53	0,59	0,62	0,11	0,10	0,16	0,11	0,15	0,18
Coeff. d'assorbimento 0,57÷0,70	0,62	0,51	0,54	0,56	0,10	0,10	0,14	0,10	0,12	0,16
Doppio vetro										
Vetro comune	0,90	0,54	0,61	0,67	0,14	0,12	0,20	0,14	0,18	0,22
Vetro 6 mm	0,80	0,52	0,59	0,65	0,12	0,11	0,18	0,12	0,16	0,20
Vetro interno comune Vetro esterno assorbente 0,48÷0,56	0,52	0,36	0,39	0,43	0,10	0,10	0,11	0,10	0,10	0,13
Vetro interno da 6 mm Vetro esterno assorbente 0,48÷0,56	0,50	0,36	0,39	0,43	0,10	0,10	0,11	0,10	0,10	0,12
Triplo vetro										
Vetro comune	0,83	0,48	0,56	0,64	0,12	0,11	0,18	0,12	0,16	0,20
Vetro da 6 mm	0,69	0,47	0,52	0,57	0,10	0,10	0,15	0,10	0,14	0,17
Vetro riflettente										
Colore chiaro	0,28									
Colore medio	0,39									
Colore scuro	0,50									
Vetri colorati xx										
Ambrati	0,70									
Rosso cupo	0,56									
Blu scuro	0,60									
Grigio scuro	0,32									
Grigio-verde	0,46									
Opalescente chiaro	0,43									
Opalescente scuro	0,37									

- F_{fog} Reduces the irradiance due to the presence of fog, goes from 1 for no fog to 0.75 for heavy fog on the site.
  On this case it would be **1.0** since there is not remarkable presence of fog in Milan during the summer condition.

- F_{frame} = 1.17 for metal frame or no frame, and 1 for other frame material. We take **1.17** as the project considers metal framing.

- $F_{dew-point}$ modifies the irradiance when the dew point temperature $T_{\text{dew-point}}$ of the project is different than 19.5 °C. Can be greater or less than 1 and follows the equation:

$$1 - (T_{dew-point} - 19.5°C)/10 * 0.13.$$

  We consider a dew point of 19.5°C for Milan in summer, so we take **1.0** for this value.

- $F_{altitude}$ increases the irradiance by 0.7% for each 300 m of altitude, its equal to:

$$1 + Project\ altitude/300 * 0.007.$$

  As Milan's altitude is 120m we could take also **1.0** for this coefficient.

Taken all the coefficients, we have:

$$C_f = F_{shad+screen} * F_{fog} * F_{frame} * F_{dew-point} * F_{altitude}$$

$$= 0.36 * 1.0 * 1.17 * 1.0 * 1.0 = 0.4212$$

We proceed to calculate the irradiance during the different hours for each window exposition:

For Southwest orientation:

$$\text{E(9h)} = I_{max}(9h) * A_{cc}(9h) * C_f = 41\frac{W}{m^2} * 0.23 * 0.4212 = 3.97\frac{W}{m^2}$$

$$\text{E(12h)} = I_{max}(12h) * A_{cc}(12h) * C_f = 181\frac{W}{m^2} * 0.5 * 0.4212 = 38.11\frac{W}{m^2}$$

$$\text{E(16h)} = I_{max}(16h) * A_{cc}(16h) * C_f = 401\frac{W}{m^2} * 0.7 * 0.4212 = 118.35\frac{W}{m^2}$$

For Northwest orientation:

$$\text{E(9h)} = I_{max}(9h) * A_{cc}(9h) * C_f = 41\frac{W}{m^2} * 0.24 * 0.4212 = 4.14\frac{W}{m^2}$$

$$\text{E(12h)} = I_{max}(12h) * A_{cc}(12h) * C_f = 44\frac{W}{m^2} * 0.19 * 0.4212 = 3.52\frac{W}{m^2}$$

$$\text{E(16h)} = I_{max}(16h) * A_{cc}(16h) * C_f = 300\frac{W}{m^2} * 0.58 * 0.4212 = 73.20\frac{W}{m^2}$$

VETRO DOPPIO CON SCHERMO INTERNO												
	h 9	h 12	h 16				telaio	vetro	tende	h 9	h 12	h 16
esp.	Irr. Corretto W/mq			Irr. Base W/mq			metal	ass.	int.	accumulo		
N	**16.92**	**18.16**	**15.69**	41.0	44.0	38.0	1.17	0.36	1	0.98	0.98	0.98
E	**132.40**	**5.37**	**3.04**	449.1	44.0	38.0	1.17	0.36	1	0.70	0.29	0.19
S	**26.59**	**93.77**	**11.76**	123.8	281.8	54.8	1.17	0.36	1	0.51	0.79	0.51
W	**4.49**	**3.71**	**156.29**	41.0	44.0	515.4	1.17	0.36	1	0.26	0.20	0.72
NE	**37.25**	**4.26**	**2.72**	170.1	44.0	38.0	1.17	0.36	1	0.52	0.23	0.17
SE	**125.41**	**48.02**	**4.00**	425.4	181.0	38.0	1.17	0.36	1	0.70	0.63	0.25
SW	**3.97**	**38.11**	**118.35**	41.0	181.0	401.4	1.17	0.36	1	0.23	0.50	0.70
NW	**4.14**	**3.52**	**73.20**	41.0	44.0	299.7	1.17	0.36	1	0.24	0.19	0.58
Orizz	**218.2**	**293.4**	**162.1**	518.1	696.5	384.9	1.17	0.36	1	1.00	1.00	1.00

Picture 2.2 – Table for Irradiance calculation, values for a double glass window taken from Manuale della climatizzazione.

Having the Irradiance value "E" passing through the window surface, we just need to multyply it by the window's area to know the total radiant flux of energy in Watts entering from that window to the thermal zone.

$$\phi = E.A$$

Formula 2.5 – Radiant flux equation

For the 3 windows of 1.25m by 3.15m facing Southwest:

$$\phi(9h) = E(9h) * A = 3.97\frac{W}{m^2} * 11.81m^2 = 46.9W$$

$$\phi(12\text{h}) = E(12h) * A = 38.11\frac{W}{m^2} * 11.81m^2 = 450.10W$$

$$\phi(16\text{h}) = E(16h) * A = 118.35\frac{W}{m^2} * 11.81m^2 = 1398.0W$$

Then we just need to add the heat transfer passing through conduction, calculated before, to the heat transfer passing through radiation, in order to get the total heat transfer passing through the window for each especific hour of the day.

$$Q_{total-window}(9\text{h}) = Q_{cond}(9h) + \phi(9h) = 29.53W + 46.9W = 76.45W$$

$$Q_{total-window}(12\text{h}) = Q_{cond}(12h) + \phi(12h) = 73.83W + 450.10W = 523.98W$$

$$Q_{total-window}(16\text{h}) = Q_{cond}(16h) + \phi(16h) = 118.13W + 1398.0W = 1516.12W$$

For the two windows of 1.25m by 3.15m facing Northwest:

$$\phi(9\text{h}) = E(9h) * A = 4.14\frac{W}{m^2} * 7.88m^2 = 32.64W$$

$$\phi(12\text{h}) = E(12h) * A = 3.52\frac{W}{m^2} * 7.88m^2 = 27.73W$$

$$\phi(16\text{h}) = E(16h) * A = 73.20\frac{W}{m^2} * 7.88m^2 = 576.5W$$

$$Q_{total-window}(9\text{h}) = Q_{cond}(9h) + \phi(9h) = 19.69W + 32.64W = 52.33W$$

$$Q_{total-window}(12\text{h}) = Q_{cond}(12h) + \phi(12h) = 49.22W + 27.73W = 76.95W$$

$$Q_{total-window}(16\text{h}) = Q_{cond}(16h) + \phi(16h) = 78.75W + 576.50W = 655.23W$$

Finally we must sum up the energy transfer through the external walls calculated on section 2.1, through internal of walls on section 2.2 (not applied on this case) and through glazed walls of section 2.3, individually for each specific hour of the analysis, finding the total energy transfer of the thermal subspace 116 during summer at 9h, 12h and 16h.

$$Q_{total}\,(\#\text{h}) = Q_{ext.\ walls}(\#h) + Q_{int.\ walls}(\#h) + Q_{glazed}(\#h)$$

$$Q_{total}\,(9\text{h}) = (1.01W + 2.47W + 1.64W + 0.13W) + 0W + (76.45W + 52.33W) = 134W$$

$$Q_{total}\,(12\text{h}) = (1.01W + 8.73W + 2.12W + 0.13W) + 0W + (523.98W + 76.95W) = 613W$$

$$Q_{total}\,(16\text{h}) = (2.72W + 11.44W + 7.69W + 0.48W) + 0W + (1516.12W + 655.23W) = 2194W$$

Locale n°	116																	
				ESTATE ore 9,00					ESTATE ore 12,00					ESTATE ore 16,00				
				trasm.			irragg.	Tra+Irr	trasm.			irragg.	Tra+Irr	trasm.			irragg.	Tra+Irr
	esp.	mq.	K	ΔT	W	ΔTe	W	W	ΔT	W	ΔTe	W	W	ΔT	W	ΔTe	W	W
Parete cieca	N		0.26			-0.7	0.00	0.00			-0.7	0.00	0.00			1.5	0.0	0.00
Parete finestrata	N		1.25	2	0	16.9	0.00	0.00	5	0	18.2	0.00	0.00	8	0	15.7	0.0	0.00
Parete finestrata (ombra	N		1.25	2	0	16.9	0.00	0.00	5	0	18.2	0.00	0.00	8	0	15.7	0.0	0.00
Porta	N		2.00			-2.4	0.00	0.00			-0.7	0.00	0.00			4.8	0.0	0.00
Parete cieca	E		0.26			2.7	0.00	0.00			9.7	0.00	0.00			7.6	0.0	0.00
Parete finestrata	E		1.25	2	0	132.4	0.00	0.00	5	0	5.4	0.00	0.00	8	0	3.0	0.0	0.00
Porta	E		2.00			11.0	0.00	0.00			16.5	0.00	0.00			6.0	0.0	0.00
Parete cieca	S		0.26			-0.2	0.00	0.00			0.2	0.00	0.00			4.3	0.0	0.00
Parete finestrata	S		1.25	2	0	26.6	0.00	0.00	5	0	93.8	0.00	0.00	8	0	11.8	0.0	0.00
Porta	S		2.00			-2.4	0.00	0.00			6.0	0.00	0.00			13.7	0.0	0.00
Parete cieca	W	2.10	0.26			1.9	1.01	1.01			1.9	1.01	1.01			5.0	2.7	2.72
Parete finestrata	W		1.25	2	0	4.5	0.00	0.00	5	0	3.7	0.00	0.00	8	0	156.3	0.0	0.00
Porta	W		2.00			-0.7	0.00	0.00			1.5	0.00	0.00			13.7	0.0	0.00
Parete cieca	NE		0.26			0.6	0.00	0.00			4.5	0.00	0.00			3.4	0.0	0.00
Parete finestrata	NE		1.25	2	0	37.2	0.00	0.00	5	0	4.3	0.00	0.00	8	0	2.7	0.0	0.00
Porta	NE		2.00			2.1	0.00	0.00			10.4	0.00	0.00			6.0	0.0	0.00
Parete cieca	SE	6.83	0.26			1.4	2.47	2.47			5.0	8.73	8.73			6.5	11.4	11.44
Parete finestrata	SE		1.25	2	0	125.4	0.00	0.00	5	0	48.0	0.00	0.00	8	0	4.0	0.0	0.00
Porta	SE		2.00			6.5	0.00	0.00			14.9	0.00	0.00			9.3	0.0	0.00
Parete cieca	SW	5.86	0.26			1.1	1.64	1.64			1.4	2.12	2.12			5.1	7.7	7.69
Parete finestrata	SW	11.81	1.25	2	29.53	3.97	46.92	76.45	5	73.83	38.1	450.15	523.98	8	118.13	118.3	1,398.0	1,516.12
Porta	SW		2.00			-0.7	0.00	0.00			0.4	0.00	0.00			17.1	0.0	0.00
Parete cieca	NW	0.88	0.26			0.6	0.13	0.13			0.6	0.13	0.13			2.1	0.5	0.48
Parete finestrata	NW	7.88	1.25	2	19.69	4.145	32.64	52.33	5	49.22	3.5	27.73	76.95	8	78.75	73.2	576.5	655.23
Porta	NW		2.00			-2.4	0.00	0.00			0.4	0.00	0.00			6.0	0.0	0.00
Parete interrato	N		0.22			-0.7	0.00	0.00			-0.7	0.00	0.00			1.5	0.0	0.00
Parete intercapedine	N		0.22			-0.7	0.00	0.00			-0.7	0.00	0.00			1.5	0.0	0.00
Parete controterra	=		0.22		0					0					0			
Porta interna	=		2.00	2	0			0	5	0			0	8	0			0
Parete divisoria	=		0.40	2	0			0	5	0			0	8	0			0
Parete asola	=		0.00	2	0			0	5	0			0	8	0			0
Parete ascensore	=		0.22	2	0			0	5	0			0	8	0			0
Parete scala	=		0.22	2	0			0	5	0			0	8	0			0
Pav su terreno	=		0.21		0					0					0			
Pav su esterno	oriz		0.29			-0.7	0	0			-0.7	0	0			1.5	0	0
Pav su loc no risc	oriz		0.29			-0.7	0	0			-0.7	0	0			1.5	0	0
Pav interpiano	=		0	2	0				5	0				8	0			
Lucernaio	oriz		1.25	2	0	218.2	0	0	5	0	293.4	0	0	8	0	162.1	0	0
Copertura	=		0	2	0	2.2	0	0	5	0	4.2	0	0	8	0	11.1	0	0
Cop verso loc no risc	=		0.18	2	0		0	0	5	0		0	0	8	0		0	0
26								134					613					2,194

Picture 2.3 – Table for summer heat transfer of thermal zone 116

Finally, to this total heat transfer through the building envelope at the different hours, it is added the value of internal gains produced in the interior of the the space at the same time, to get the total cooling power needed.

$$Q_{total}(9\text{h}) = Q_{external}(9h) + People\ gain + Lighting\ gain + Equipment\ gain$$

For people gain, it is considered that each office will be occupied by four people. The gain of each people is taken according to the activity they perform, based on the *Tab 3.30* of the *"Manualle della Climatizzazione"* (see *Chapter 1.5*) According to it, for people performing office work, it is produced 84W of sensible gain by each, giving a total space load of 336W for the thermal space 116.

Lighting gain usually is considered as 10W/m^2 giving a total load of 255W for the space, since the thermal zone 116 has an area of 25.5m^2.

For equipment gain, it depends also on the type of use of the space and the equipment placed there, on *tab 3.34* of the *"Manualle della Climatizzazione"* (see *Chapter 1.5*) there is located the amount of energy is produced by each different type of equipment. Having this value and the area of the thermal zone we could get an approximate value of 25W/m^2, making it 637.5W for the space of thermal zone 116.

Summing all the mentioned loads with the already calculated external energy transmission, the calculation would be:

$$Q_{total}(9\text{h}) = 134W + 336W + 255W + 637.5W = 1362.52W$$
$$Q_{total}(12\text{h}) = 613W + 336W + 255W + 637.5W = 1841.42W$$
$$Q_{total}(16\text{h}) = 2194W + 336W + 255W + 637.5W = 3422.18W$$

This states the amount of cooling power needed to be supplied by the HVAC for this specific room during each specific hour, in order to counter the gains of the thermal space. Repeating the same process for all the different thermal zones of the building and summing them according to each specific time, gives us the total HVAC plant cooling power needed to maintain the several spaces on comfort during this summer condition.

At the end we take the maximum power value between the three different times and consider it as the pre-sizing value that is needed to be provided for our cooling equipment.

It is important to mention that the load required for ventilation has not been considered yet, the ETD method stated in the Manualle della Climatizzazione only defines the load required to counter the losses or gains through the building envelope while also considering the internal gains only for the cooling power calculation. Therefore, to the final cooling and heating power value found, it is still needed to add the amount of power required to cooldown or heat-up the exterior air to the interior set points conditions of temperature, 20ºC for winter and 24ºC or 26ºC for summer. This value is usually approximated on the preliminary phase of the project to 10W for each m^3/h of air supplied, on the following design phases a more detailed value will be considered to get a more precise calculation of the maximum required thermal power needed to be supplied by the HVAC system.

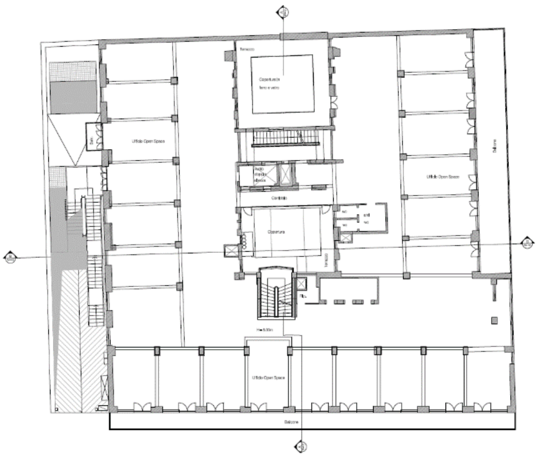
2. Methodology for HVAC pre-sizing using Energy modelling software IES-VE

For the modelling process there are several steps that need to be followed:

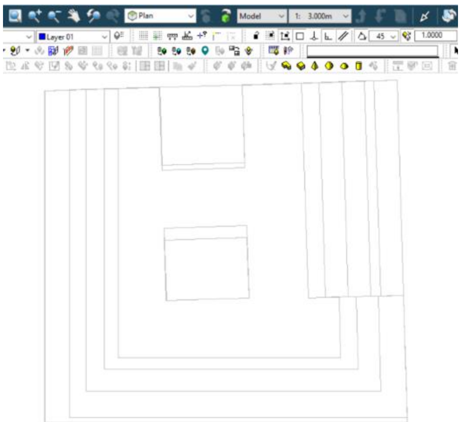
1. Building Geometry modelling.
2. Climatic zone definition and orientation of the building.
3. Input of the energy properties of the materials.
4. Creation of the thermal templates that define the energy behaviour inside each thermal zone and the comfort set points that need to be achieved by the HVAC system.
5. Definition of the basic configuration proposed for the HVAC.
6. Setting up of the simulation settings, as the output variables to be plotted and the following analysis of these.

2.1. Building Geometry Modelling

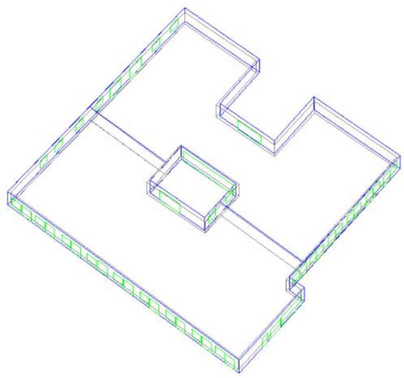
Taken the architectural plans as reference, a simplified dxf plan file is created with the essential geometry of the building, to be imported on IES VE software. There, the external envelope and internal division of thermal spaces are modelled in the software.



Picture 2.1 – Architectural plan of the building on CAD format.



Picture 2.2 – DXF plan of the building geometry imported on IES-VE



Picture 2.3 – One floor of the building modelled on IES-VE taking the DXF as reference

Picture 2.4 – 3D Model of the building on IES-VE

2.2. Climatic zone definition and orientation of the building.

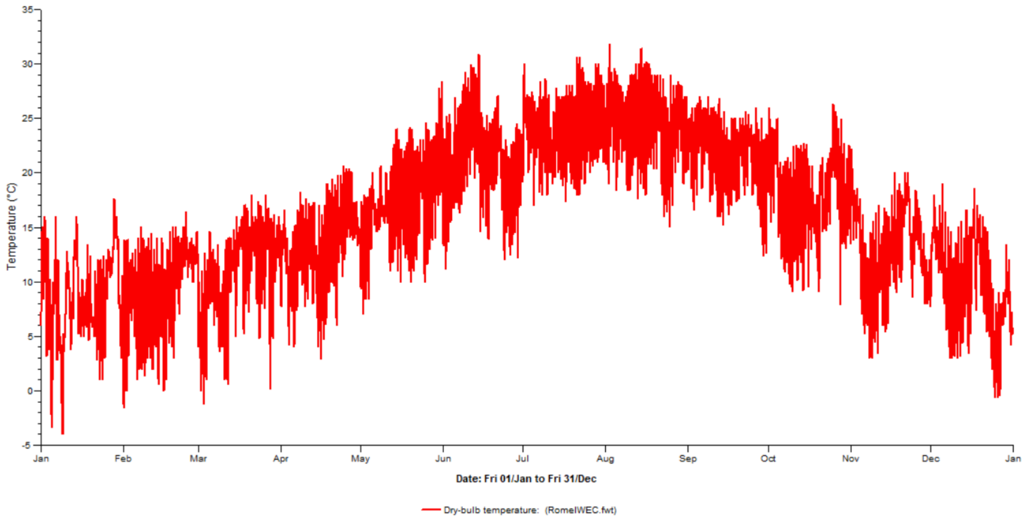
For the Energy modelling was selected an office building located in Rome which renovation was performed by Lombardini 22 Spa.

The main tool for the energy analysis is the Weather Data File, which contains the main climatologic parameters of the site, such as temperature, radiation on every direction, humidity, wind velocity etc,.

It is basically the “Typical Meteorological Year Data” containing an hourly value for each climatologic parameter for an entire year. Each of these values is the measured hourly value closer to the average value of each specific hour, that were measured on a climatological station, usually in a range of 10 years.

For the case of this building, was selected a weather data file of the city of Rome, containing 8760 values (1 for each hour of a year) of temperature, radiation, humidity… that were measured near where the building is located.

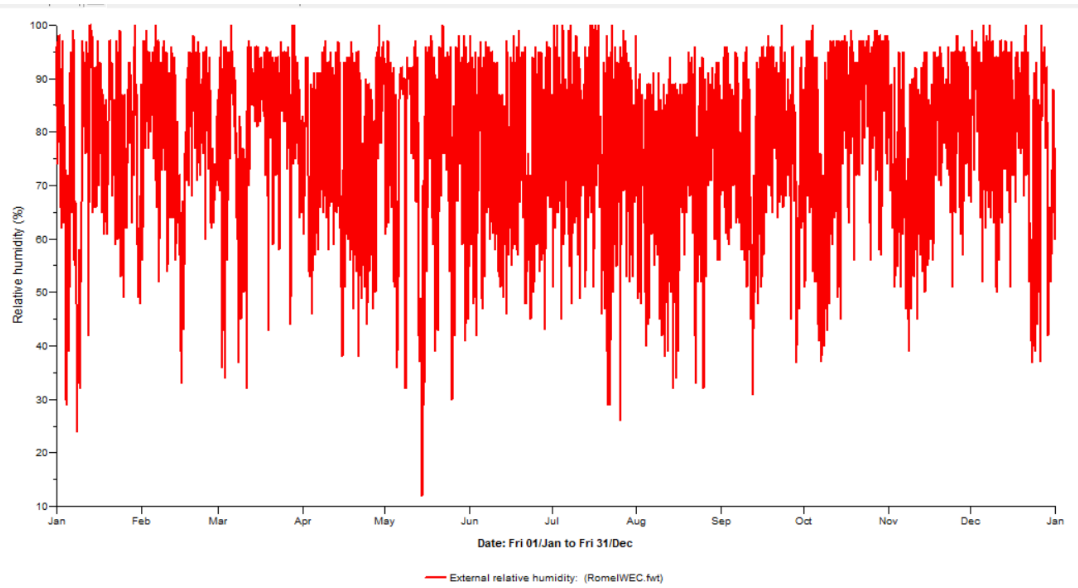
Among these parameters, the external air temperature is one of the most important ones since it states the energy transfer by conduction through the building envelope, due to the difference in temperature between inside and outside of each thermal zone.



Picture 2.5 – Dry-bulb external temperature from Rome’s weather file

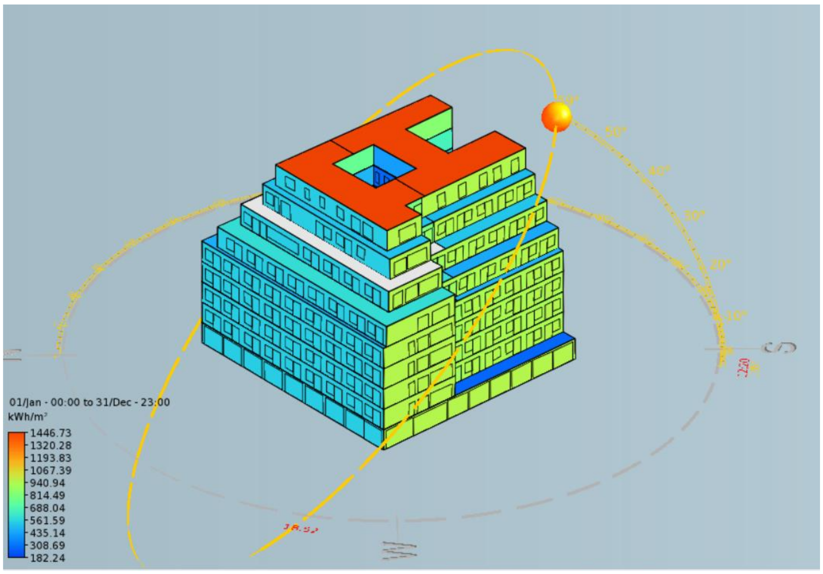
Rome’s climate is Mediterranean, having mild winters with only couple of days below 0º Celsius degrees, very nice spring and fall temperatures between 17ºC and 24ºC and warm to hot summers, reaching 32ºC as maximum at the end of July or beginning of August.

It is remarkable its high relative humidity, above 60% most of the year, making it hard to maintain below the comfortable levels, inside the building space.

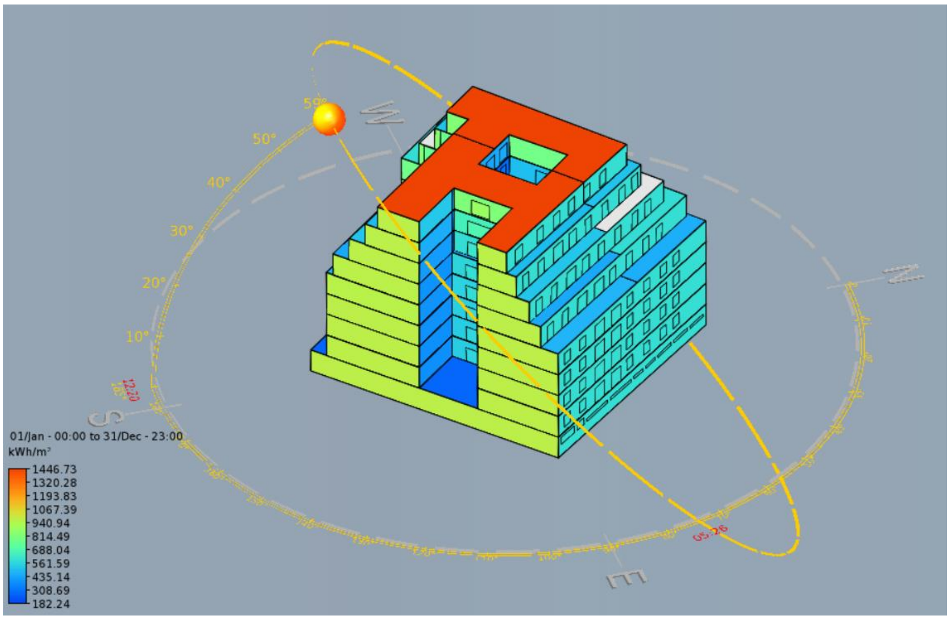


Picture 2.6 – External relative humidity from Rome's weather file

The solar radiation takes high importance in Rome, especially during summer analysis, since it basically defines the cooling needs as it is the greatest source of heat gain during that time of the year. As we saw previously, the air temperature does not get into really high levels in Rome, maintaining low the heat transfer by conduction, while giving more importance to the heat transfer getting inside the building as radiation through the transparent surfaces. Therefore it is very important to orientate the building on the model as it is in reality, in this case the true north is located almost on the corner between two of the facades.



Picture 2.7 – Solar Radiation from west orientation, during the entire year



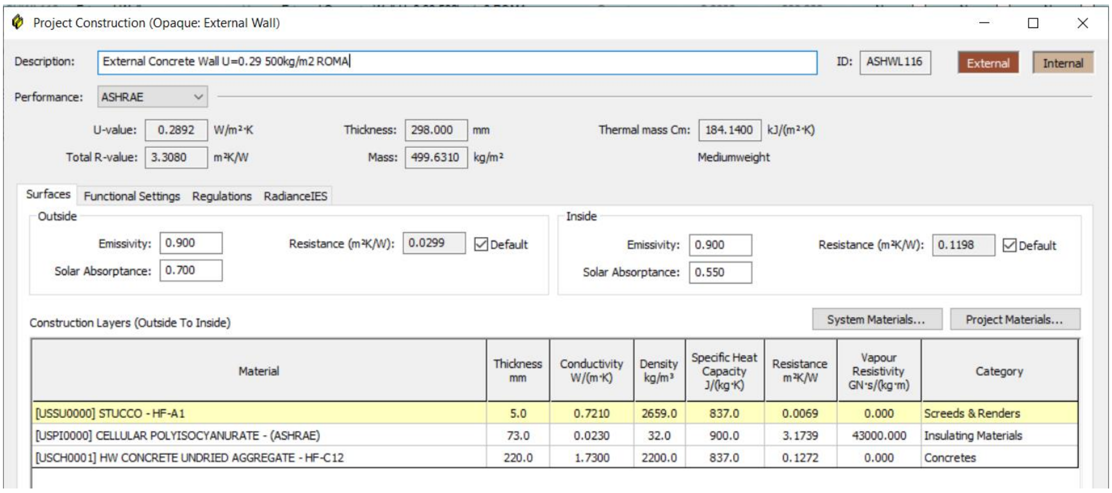
Picture 2.8 – Solar Radiation from east orientation, during the entire year

2.3. Input of the energy properties of the materials.

As we saw on the Carrier method explained on *Chapter 1*, the thermal properties of the building components define the heat that will pass through them. The thermal conductivity of walls and glazes defines the energy transmission by conduction, the mass of a glass the amount of heat that is accumulated or stored in it, the G-value and Shading Coefficient of a glass, the energy passing through it as solar radiation, and so on.

As IES-VE software already has in its code all of the several energy/heat transfer equations needed, we just need to define the thermal properties of the building components and it will calculate the corresponding energy transmission. This is made creating the stratigraphy of the building envelope to assign it to the model.

- External Walls:



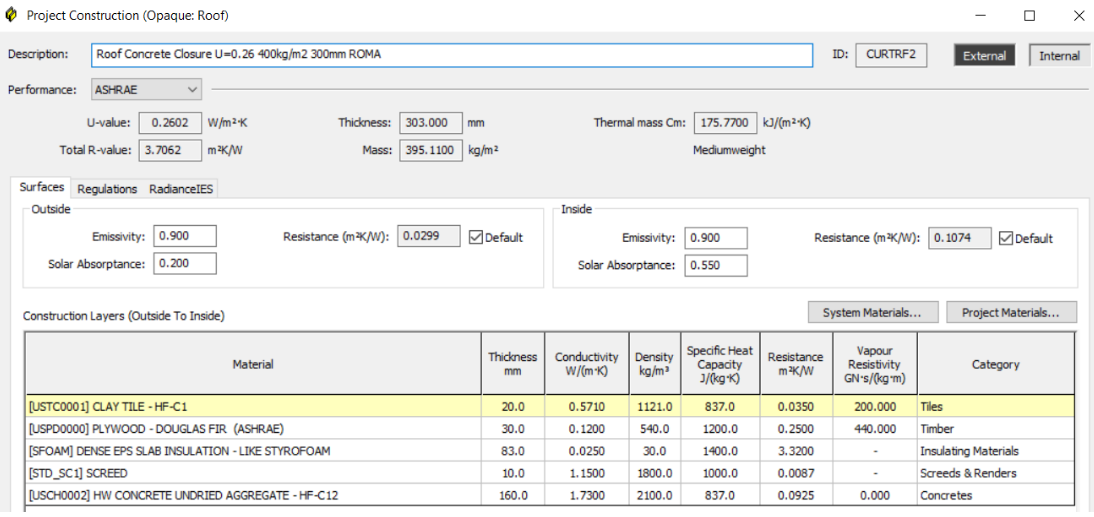
Picture 2.9 – External wall stratigraphy considered in IES-VE

The external walls of the building were considered as having an U-value equal to 0.29W/m^{2}K and a mass of 500kg/m^2, therefore we created a very simple wall of three layers: Stucco on its external surface, 73mm of cellular polyisocyanurate as insulation and 220mm of heavy weight concrete. These material's energy properties as conductivity and their thickness along with their density, create a wall with the previous mentioned U-value and mass needed.

Usually during the first phases of a building construction or renovation project (when the HVAC pre-sizing takes place), the exact typology of layers and their characteristics are not defined yet, so the important thing during the energy modelling is to respect the overall thermal behaviour of the components, as the mentioned U-value which is usually defined by law according to the building location, and the mass, which is a more or less standard and do not varies a lot on the future project phases.

- Roof:

The building roof designed in the architectural phase had around 350kg/m^2 of mass with an U-value of 0.26W/m^2. Therefore, 20mm of clary tyle, 30mm of plywood, 83mm of dense EPS as insulation, plus the 160mm of concrete combined create the building roof component with the mentioned properties.



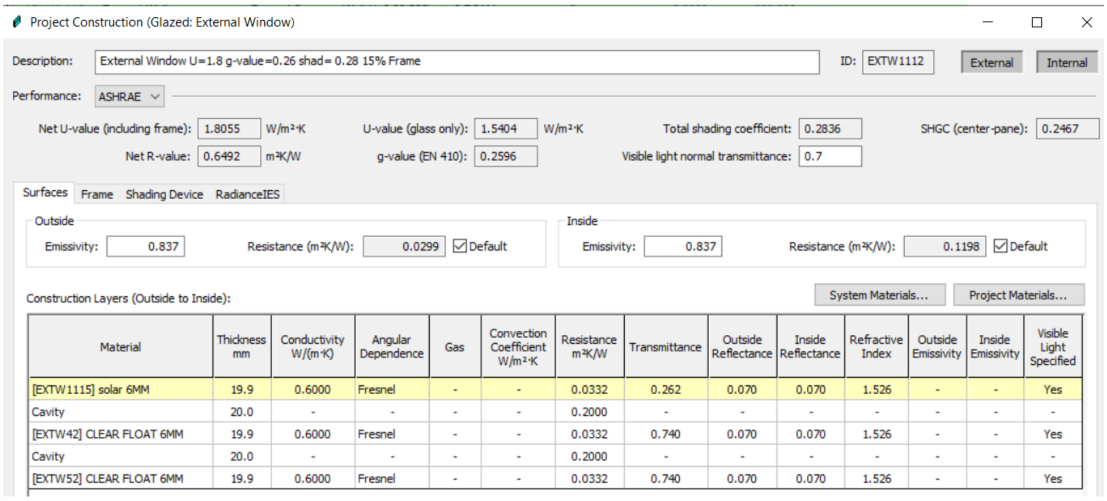
Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[USTC0001] CLAY TILE - HF-C1	20.0	0.5710	1121.0	837.0	0.0350	200.000	Tiles
[USPD0000] PLYWOOD - DOUGLAS FIR (ASHRAE)	30.0	0.1200	540.0	1200.0	0.2500	440.000	Timber
[SFOAM] DENSE EPS SLAB INSULATION - LIKE STYROFOAM	83.0	0.0250	30.0	1400.0	3.3200	-	Insulating Materials
[STD_SC1] SCREED	10.0	1.1500	1800.0	1000.0	0.0087	-	Screeds & Renders
[USCH0002] HW CONCRETE UNDRIED AGGREGATE - HF-C12	160.0	1.7300	2100.0	837.0	0.0925	0.000	Concretes

Picture 2.10 – Roof stratigraphy considered in IES-VE

- Windows:

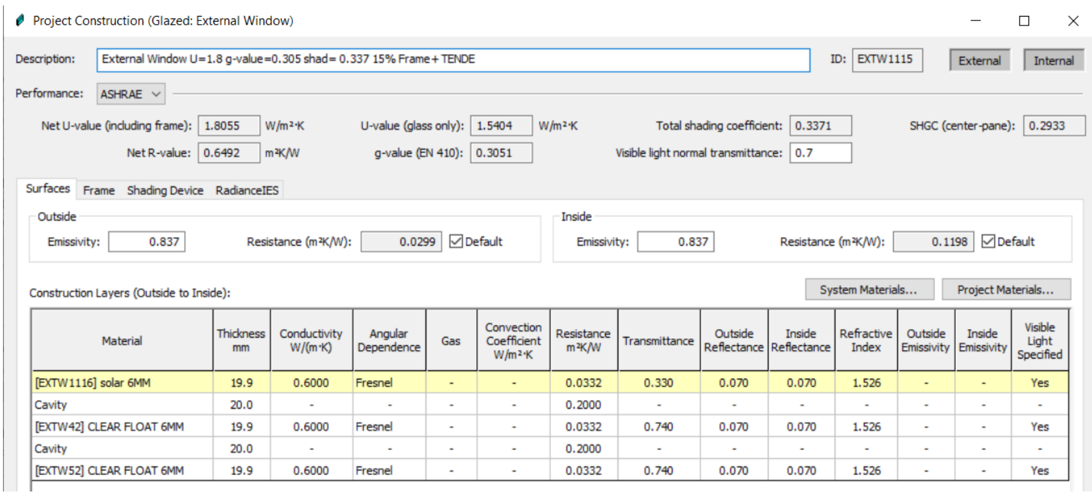
The window's thermal properties could be the most important part of the building envelope, since they represent a great percentage of the façade area while having higher U-value than the external opaque wall, making it easier for the heat to enter or leave the interior space by conduction through them. Also their solar performance stated by the G-value and Shading coefficient determine the amount of solar radiation entering to the inner space. For this project, were selected windows with a Shading coefficient of 0.28, U-value of 1.8 W/m^{2}K and approximately 15% of frame area, values selected by the architects during the design phase.

Therefore, a triple glazing window with the following thermal and solar properties matches with the requirements.

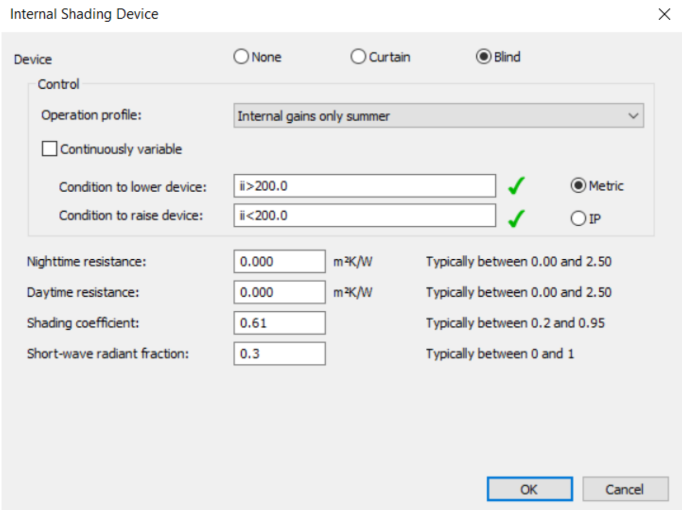


Picture 2.11 – Window stratigraphy considered in IES-VE, including the effect of the venetian blind in the window's properties

This shading coefficient value considers the shading device as always present in the window; it is an interior venetian blind. To make a more realistic approach, it was created also another window construction taking out the effect of the shading inside the glass, while consider it as external, that is present only when the solar radiation value gets above the 200W/m^2.



Picture 2.12 – Window stratigraphy considered in IES-VE, removing the effect of the venetian blind in the window's properties

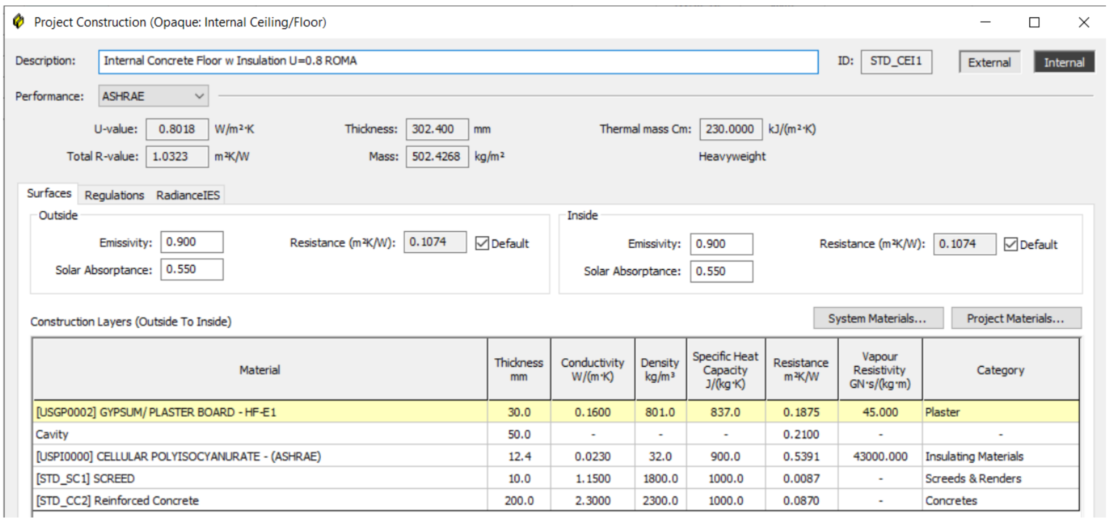


Picture 2.13 – Properties of the shading device considered in IES-VE which are applied on the windows only when the specific value of solar radiation is exceeded

As it is explained on the following chapters, different models were created, one with the shading device always present as it is considered on the static calculation made on the Carrier's method excel, while other that the presence of the shading depends on the solar conditions, since we have the possibility of implanting this in the dynamic model. The comparison between those is shown in the third chapter.

- Internal ceiling/floor:

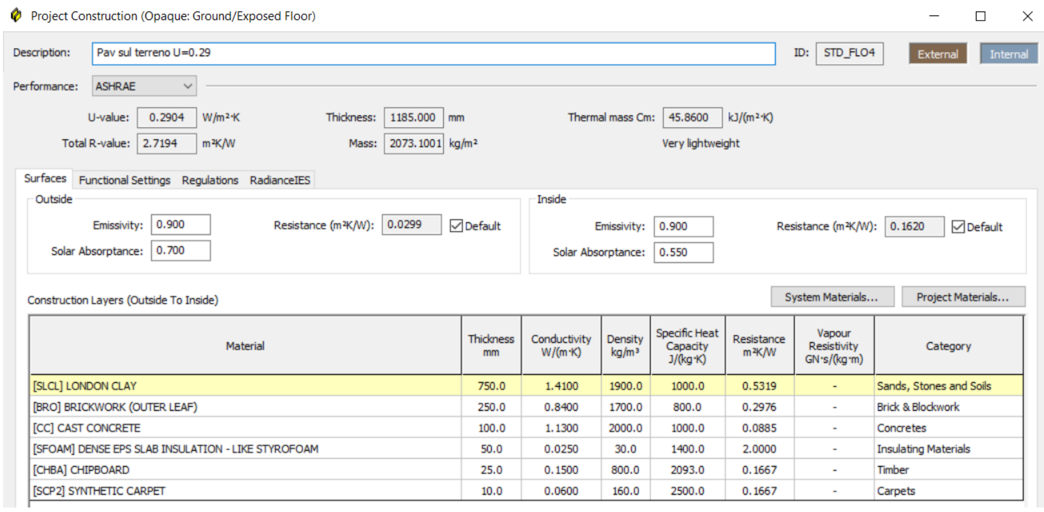
Since the interior conditions of every floor are different, there will be vertical transmission of energy inside the building space, the thermal properties of the ceiling are important to determine this heat transmission. An U-Value of 0.8 W/m^2 and a mass of around 500 kg/m^2 was determined.



Picture 2.14 – Internal ceiling/floor stratigraphy considered in IES-VE

- Ground exposed/floor:

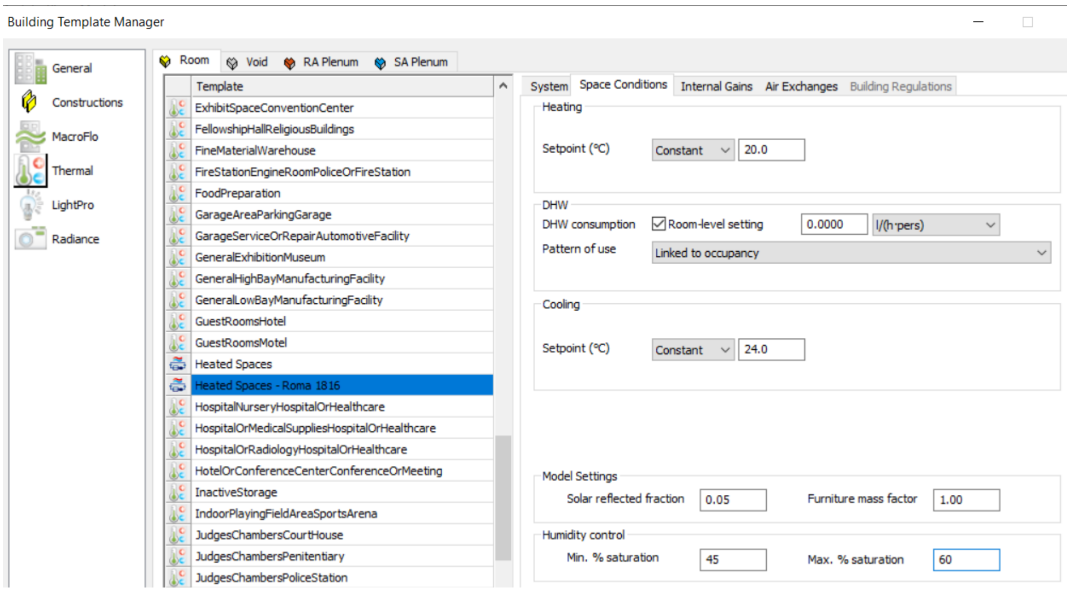
As there is heat transmission between the external air and the interior spaces, as well as between floors, there is also a conduction between the ground-floor of the building and the ground where the building is located. The U-value of the ground exposed floor determines this heat exchange, it was considered as having a value of 0.29W/m^{2}K, and its stratigraphy is defined below.



Picture 2.15 – Ground exposed floor stratigraphy considered in IES-VE

2.4. Creation of the thermal templates.

A thermal template is an assignment given to each thermal space, that defines how is the thermal behaviour inside of it. It defines the main desirable settings that will be applied to the HVAC system, and consequently to every thermal zone of analysis through it, as their temperature and humidity set points, required ventilation and air exchanges, while also and very importantly, what is the value and the fluctuation of the internal gains inside each thermal space.

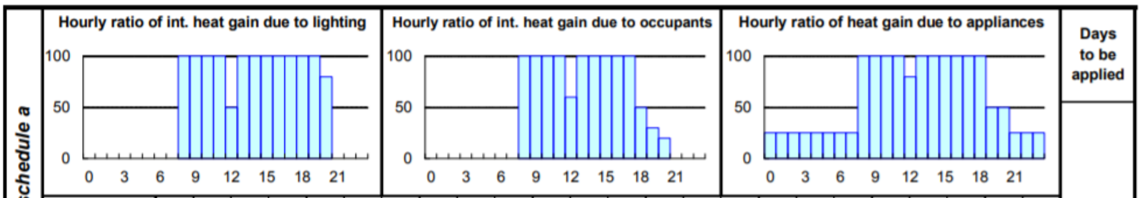


Picture 2.16 – Thermal template with the Space Conditions of the thermal zones

The desirable comfort conditions of heating and cooling for the interior spaces of the building were previously defined by the general designers of the building according to law and necessities of the future occupants. For winter, the minimum interior temperature is set to 20ºC from 1st of November to 15th of April with a range of acceptance of +/- 1ºC, while in summer 24ºC +/- 1ºC, both for the 12 hours of working time of the HVAC, planned to be the available time of the building itself, which is from 8am to 8pm from Monday to Friday, during the entire year.

The relative humidity during all the year is set to be in the range between 45 and 60%, while the minimum required outside air set to 39.6 $m^3/h \approx 11$ *l/s* per person.

The internal gains are stated, inserting the value for each specific type of them: People, lightning and appliances, and their specific hourly variation during the day. For this task, one model was made taken the profiles from the norm ISO18523 showed next, specific for an office room, inside an office building, while other, was made without an hourly variation on the gains, simply the fixed value from 8am to 8pm. Later in the document it is shown the implication of this internal gains variation on the cooling and heating demand of the building.



time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Days to be applied
Simultaneous usage ratio	0	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	Week days
Int. heat gain due to lighting	0	0	0	0	0	0	0	0	100	100	100	100	50	100	100	100	100	100	100	100	80	0	0	0	
Int. heat gain due to occupants	0	0	0	0	0	0	0	0	100	100	100	100	60	100	100	100	100	100	50	30	20	0	0	0	
Int. heat gain due to appliances	25	25	25	25	25	25	25	25	100	100	100	100	80	100	100	100	100	100	100	50	50	25	25	25	

Picture 2.17 – Internal Gains profiles from ISO18523

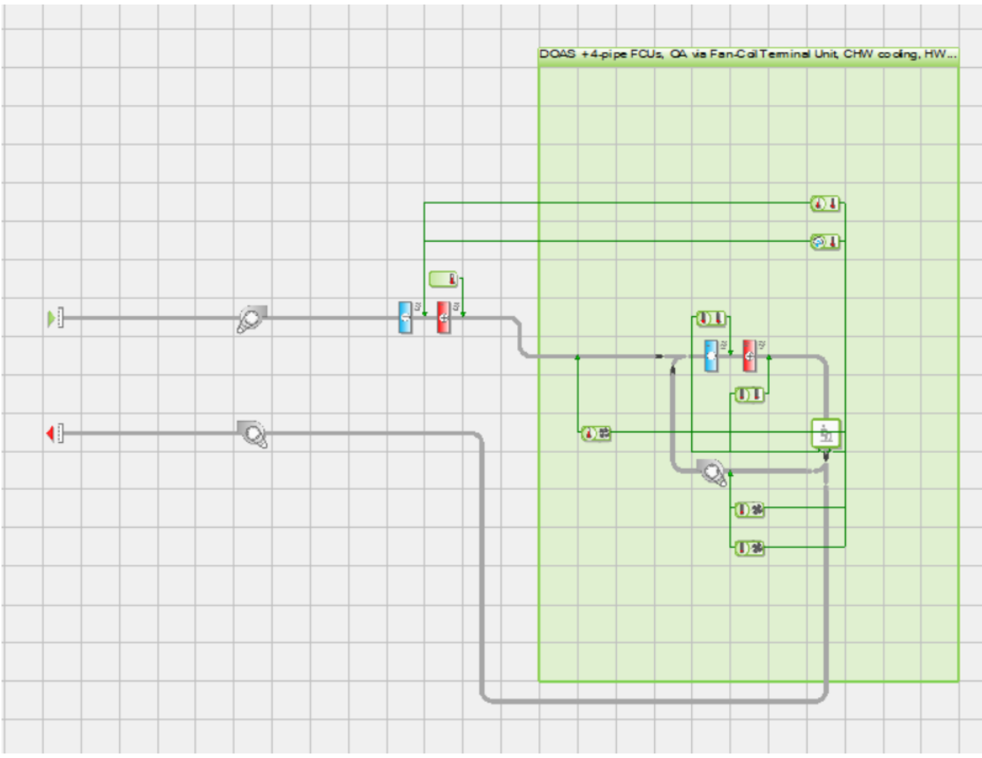
People gain is set as 64W of sensible and 69W of latent load per person, with an occupacy rate of 11.24m² per each one of them, applied in the entire building interior space.

Lightning gain is 5W/m² and equipment 10 W/m², the three following the previously showed profiles for the most detailed model made, while with the total fixed value for a simplified one, intended to follow the carrier method methodology.

2.5. Proposed configuration for the HVAC system

Since its preliminary phase, the mechanical engineers on charge of designing the HVAC plant of the building though about implementing a system conformed by a global Air Handling Unit (AHU) that will pre-heat or pre-cool the exterior air, prior to transfer it to each thermal zone's Fan Coil Unit, that will set the volume of air to the desirable output temperature conditions. This kind of system was the one modelled on the software, on its essential schematic way, showed below.

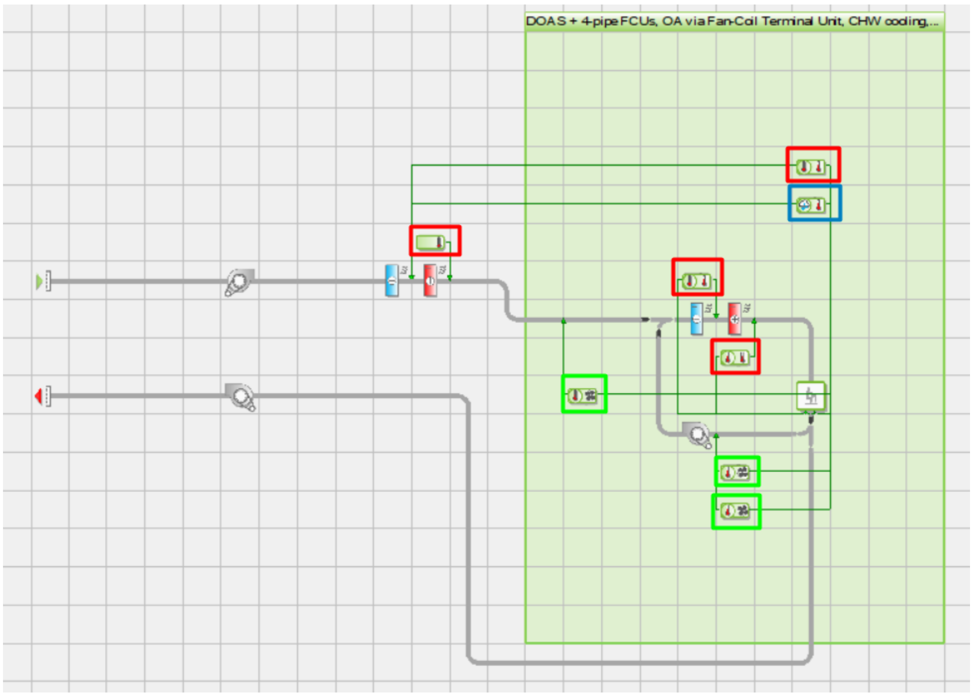
The whole purpose of the process is to know the required value of thermal power that the whole HVAC should be able to provide and to extract from the building during the maximum heating and cooling peaks.



Picture 2.18 – HVAC Schematic configuration implemented in IES-VE

The controllers that are placed on the system have the task of regulating the functioning of the HVAC in order to maintain the stated thermal conditions assigned on the thermal templates.

The first typology of controllers (on red colour) work regulating the amount of heat that the cooling and heating batteries should provide to the air, in order to get every room air to the desirable comfortable temperature conditions, this is made controlling the leaving temperatures of the UTA and each room's fan coil unit, that is why they are placed right in the leaving node of each one of them.



Picture 2.19 – HVAC Controllers of the system

There is also one control (blue colour) regulating the leaving temperature of the cooling battery of the UTA, in order to set the leaving air cooler, if needed, decreasing in this way the moisture content to fit the relative humidity setpoint while it is getting near the maximum comfortable condition.

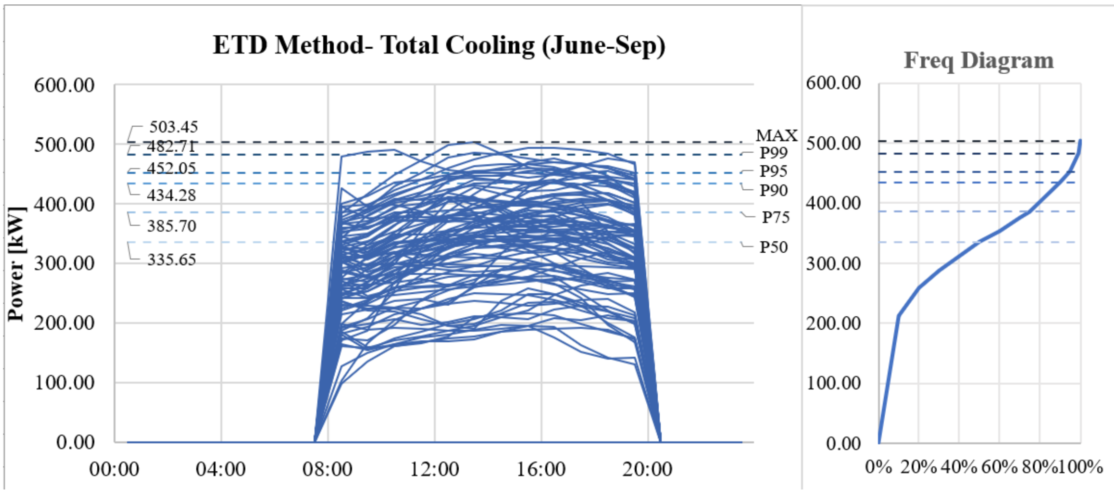
While the last typology of controllers (green colour), regulate the volume flow of air that is entering from outside first, to satisfy the minimum of 11 L/s of outside air by person, and second, the amount that is recirculated and heating or cooling again, to maintain each room into the settled temperature conditions.

2.6. Simulation settings, outputs, and analysis of results

Three different model configurations were made, in order to see the effect of the different considerations on the results given by them.

- ETD Method model:

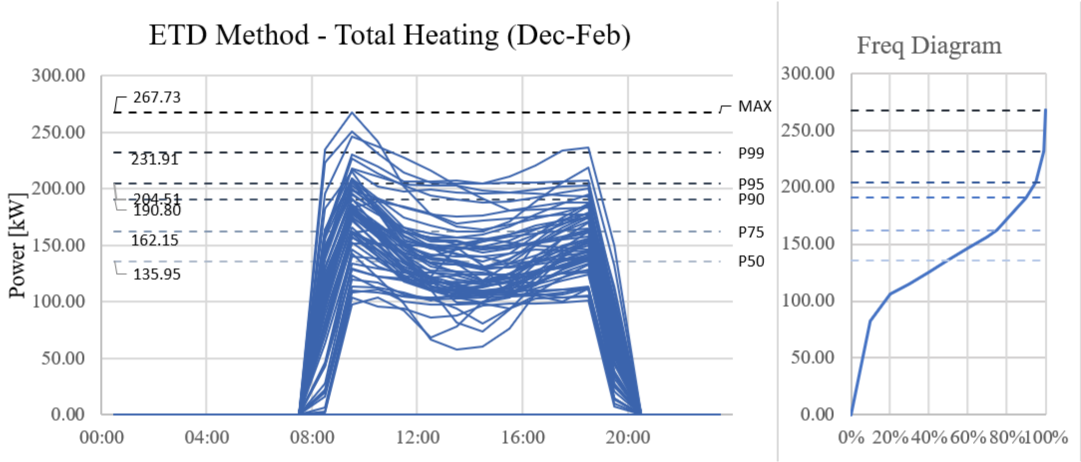
One is following the ETD Method that do not consider the internal gains during winter, this is done trying to consider the worst-case scenario of maximum heating power needs. Also the ISO profiles of the loads explained before were not considered, but just a constant value of the three types of internal loads during the day between 8am and 8pm. The total cooling and heating power needed are showed next alongside the frequency diagram of it.



Picture 2.20 – Total cooling power demanded hourly by the ETD Method Model, from June to September

Annual cooling load= 61.29 kWh/m^2.

As we can see on the graph above, the model made according to the ETD method considerations, explained before, gave a result of 503.45kW of maximum cooling power needed. With a percentile 50 (of the HVAC functioning hours) in 335.65kW, meaning that half of the hours between 8am and 8pm, during the months of June until September, presented a cooling need above this threshold, which is quite high. In the frequency diagram on the right side, is shown that there is an almost proportional distribution of values from 200kW, represented by the percentile 10, until 434.28kW, the percentile 90. Also it is remarkable that the upper part of the graph, which represents the cooling power peaks, present quite flat shape, without any distinctive hourly peak on the values.



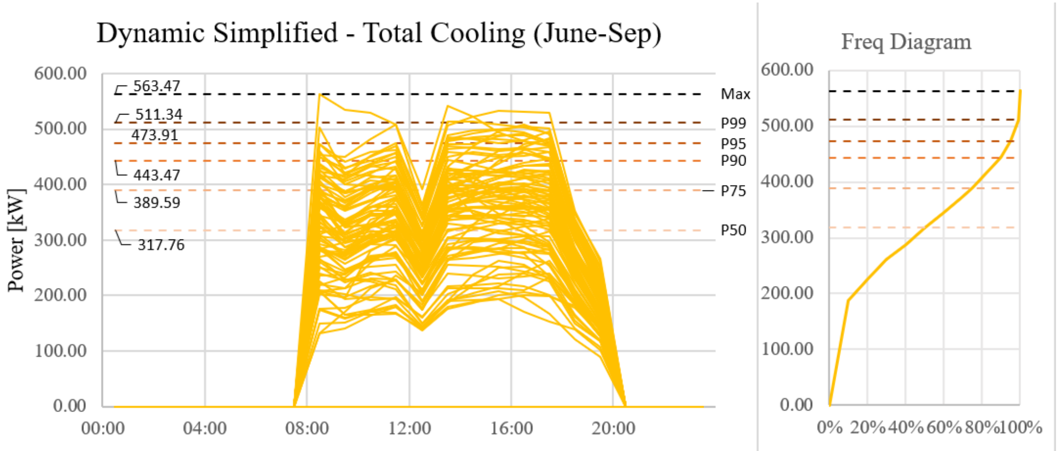
Picture 2.21 – Total heating power demanded hourly by the ETD Method Model, for the days of December to February

Annual heating load= 22.46 kWh/m².

On the other side, the heating power diagram of the same model present a less symmetric configuration. There are some remarkable hourly peaks, around 9am, the highest one, while at 7pm, the second, these hours are consistent with the starting and ending working time of the HVAC system. The first peak is explained due to the fact that the HVAC is turned off during the entire night, so the building gets colder, and when the system is turned on again during the next morning at 8am, it needs to heat up at its maximum power all the interior air with a greater ΔT in order to get the interior air condition to the comfortable temperature level, while during the rest of the day the interior air temperature is already higher, decreasing the heating power need from the system.

The peak at 7pm is because after the 2pm, the exterior air in Milan during winter, starts to decrease its temperature, so it will demand every passing hour more power from the heating coil, continuing in this way, until the end of the working time of the system at 19:30h, right before it starts to decrease the heating power provided, until reaching a value of 0 at 20h or 8pm, when is getting off again.

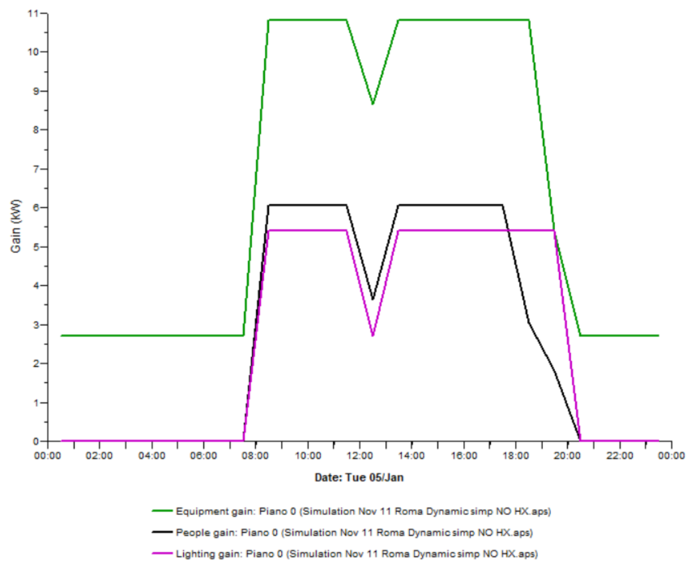
- Dynamic simplified model:



Picture 2.22 – Total cooling power demanded hourly by the Dynamic Simplified Model, for the days of June to September

Annual cooling load= 62.26 kWh/m^2.

The second model configuration was following the ISO profiles explained on the *Chapter 2.4*, they govern the behaviour of the internal gains and as we see on the graph above, also the behaviour of the cooling power needed. They were applied in the model as W/m^2 and the total value is shown in the graph below. (5.6W/m^2 for people, 10 W/m^2 for equipment and 5 W/m^2 for lightning)

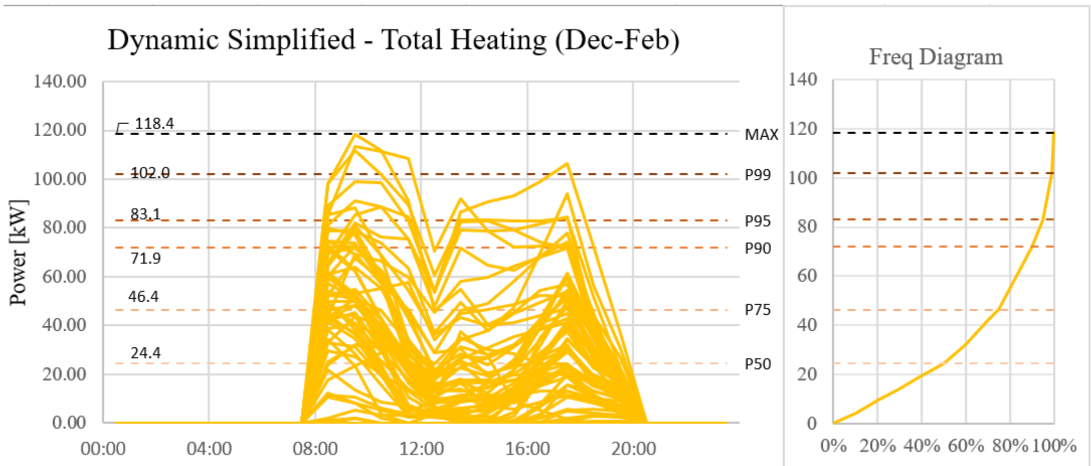


Picture 2.23 – Internal gains profiles from ISO18523 implemented on IES-VE in the Floor 0 of 1083.13m^2.

On the graph is shown the internal gains of the Ground Floor of the building applied on the Dynamic Simplified and Dynamic Complete models. Instead of having a constant value from 8h to 20h as in the ETD model, they fluctuate as the norm (ISO 18523) considers would be the approximate real behaviour of them during a normal office day. As it is an office building, the decrease on the load at midday is explained by the normal lunch time of the office workers, when 40% of them will leave the building space, decreasing in this way, the people load they create, while also needing less lightning and equipment, due to their same absence.

The norm also considers that certain percentage (25%) of the appliances load remain even during the night, probably because some electric equipment as telephones or Wi-Fi router, remain working even after the office building is empty, this will create a higher peak at early morning since, the system will need to cool down all the heat that was accumulated during the night by this internal load.

On the yellow graph is shown that the cooling power follows more or less the same profiles of the internal load, decreasing the overall value at midday, while giving a maximum of 563.47kW at 8am, not too much far from the peak of 1pm, meaning that both are related to the rise of internal load at 8am and 1pm according to the profiles. The frequency diagram shows a proportional distribution of the loads from 200kW, more or less the percentile 10, until 473kW of the percentile 95. The upper 5% of the most demanding power is a bit separate from the percentile 95, increasing in 40kw from percentile 95 to 99, and 52kW from percentile 99 to the maximum value, implying that the peak is quite isolated respect to the total number of days. The total energy load consumed by the building in cooling is about 1kWh/m^2 more than the EPD Method model, even having remarkable higher peaks, which means the internal gains' profiles control the peaks of power, but not the overall energy consumed by the system, which is more or less stable.



Picture 2.24 – Total heating power demanded hourly by the Dynamic Simplified Model, for the days of December to February

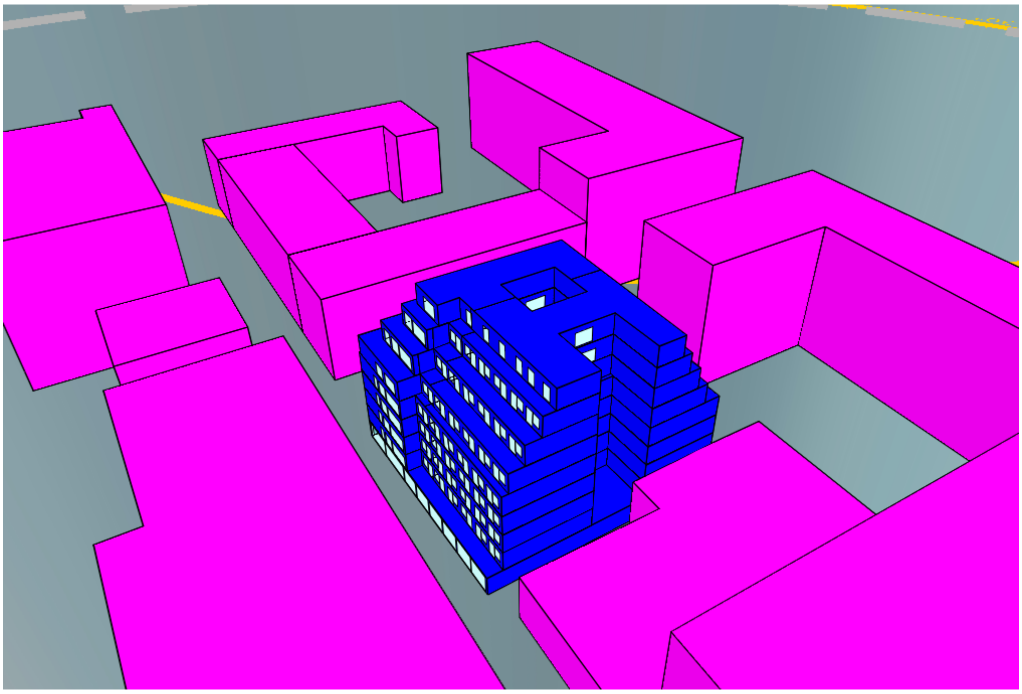
Annual heating load= 4.13 kWh/m^2.

On the heating coil, we see again a remarkable peak of power at 9am, due to the absence of heating during the night which implies an overwork of the system as soon as it is turned on during the morning. The loads are less well distributed, being quite condensed at low powers, with 24.4kW of percentile 50 and 46.4 kW at percentile 75, this due to the presence of internal gains during the winter days, decreasing a lot the required heating need overall during the year.

- Dynamic complete model:

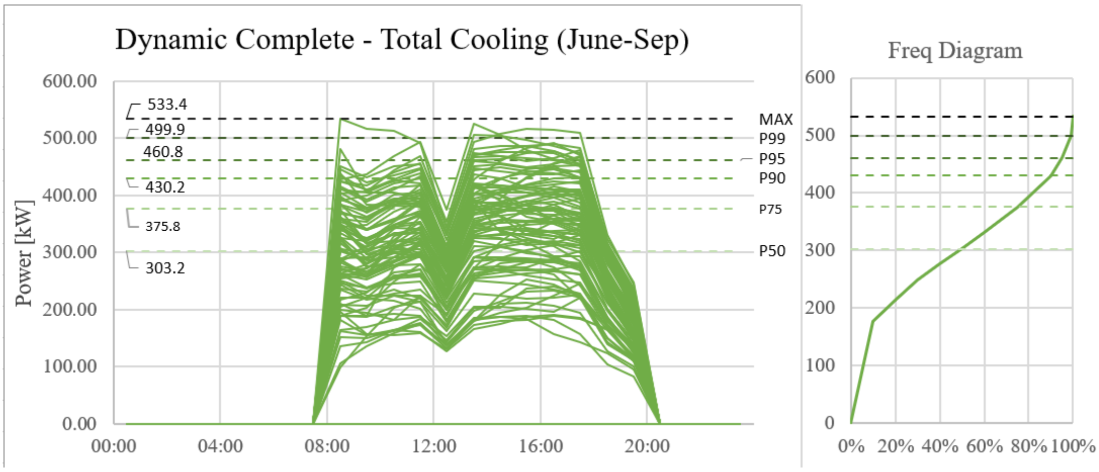
Finally there is the complete model, which as the simplified one considers the ISO profiles of the internal gains and implement them during wintertime, while also considers the surrounding buildings that take place in the city of Rome next to the building of analysis, producing indirect shading to it. These were modelled in IES-VE as volumes, with the approximate hight and plan dimensions, using as reference Google Earth and an online tool called CADMapper.

Picture 2.25 – Google Earth photo of the building area in Rome, Via Alessandria 220



Picture 2.26 – Adjacent buildings on purple, modelled on IES-VE next to the building of analysis

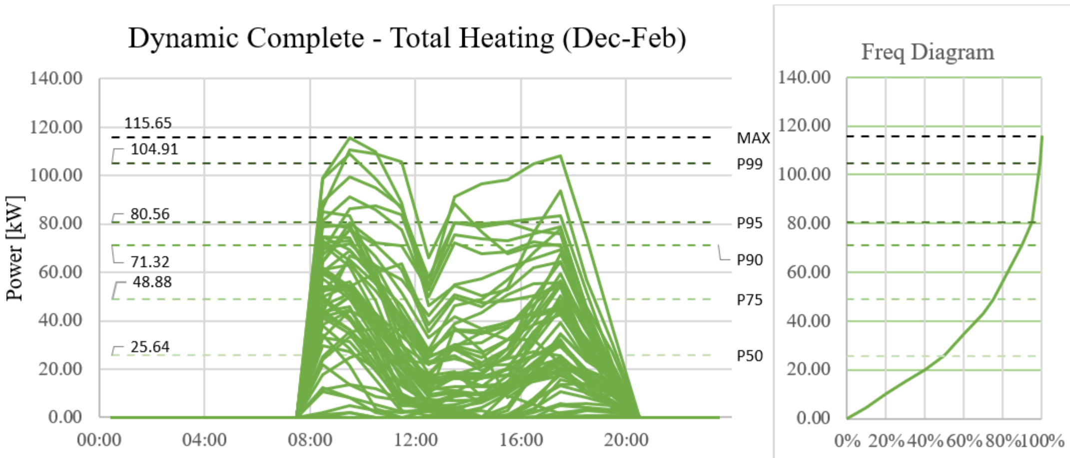
Also the venetian blind that its effect is included on the window shading coefficient in the rest of the models and in the Excel file used for ETD Method implementation, in this complete model was removed as fixed effect and only applied when the solar radiation present on the windows exceeds the value of 200W/m^2, as it was explained on the *Chapter 2.3.* This simulates a more realistic behaviour of the energy that is entering to the building, since the blinds that are operated manually for the people inside the office building only are lowered down when the incident radiation gets to really high levels, otherwise they are generally preferred up, in order to catch some natural sunlight by the office workers.



Picture 2.27 – Total cooling power demanded hourly by the Dynamic Complete Model, for the days of June to September

Annual cooling load= 59.4 kWh/m^2.

In this model the required maximum cooling load is 533.4kW, presenting a daily profile following the one of the internal loads, as it was also the case of the simplifying model, since the internal gains and their daily fluctuation clearly define the cooling needs spectre of the building. There is a constant distribution of the frequencies between the percentile 10 with a value of approximately 180kW all through the percentile 90 with a value of 430.2kW. Also a remarkable separation of the higher 1% of the most demanding cooling days takes place, since the percentile 99 is located at 500kW of power, while the maximum value is more than 30kW above it, at 533.4kW. Nevertheless, its annual total cooling load is the lowest one among the three models with 59.4kWh/m^2, due to the effect of the context of the other buildings surrounding and blocking part of the solar radiation, as it happens in the reality.



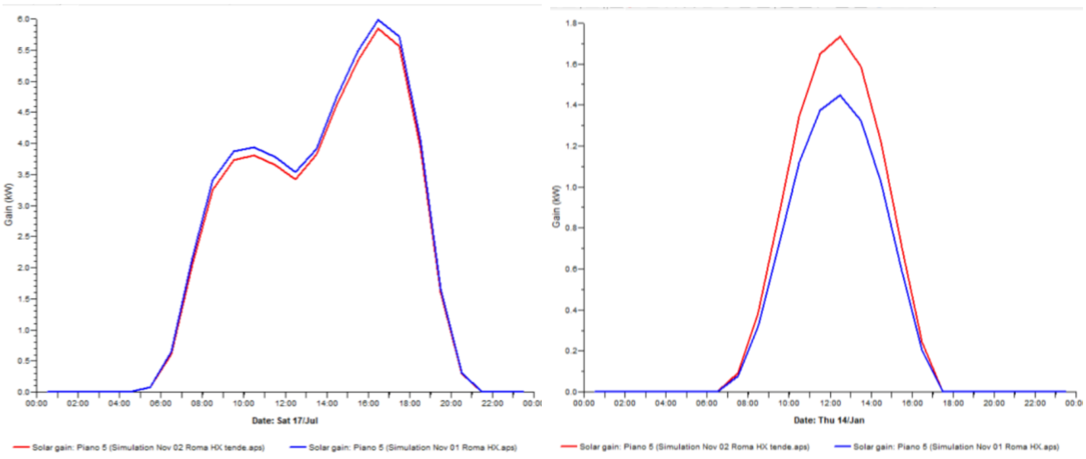
Picture 2.28 – Total heating power demanded hourly by the Dynamic Complete Model, for the days of December to February

Annual heating load= 4.22 kWh/m^2.

The annual heating load of this model present a bit higher value compared with the simplified one, showing the effect of the solar radiation of the sun even during winter, in reducing the heating needs. As the sun is down in winter, its radiation is blocked by the surrounding buildings, avoiding that it gets to the inner space, which in the other models, help on the decreasing the heating load.

The frequency diagram shows an exponential behaviour of the hourly heating values, meaning that most of the hours present low heating needs, while the most demanding days are quite isolated and not so frequently repeated.

On the graphs below we see the effect of considering the shading device not as included permanently in the window's properties but only when a certain value of solar radiation is exceeded. While during the summertime both the dynamic simplified model (blue colour line) and dynamic complete one (red colour line) present more or less the same solar gains, during wintertime the complete model presents higher values, due to the fact that the shadings are not present during the low solar radiations received by the building during those winter days. In this way, is helping up the building in reducing the heat gains, getting as much solar energy as possible when needed in winter, and continue blocking it when its necessary in summer.



Picture 2.29 – Solar Radiation entering in the first floor at July 17th(left) and January 14th (right) on different models, with the blinds included in the glass (blue) and shading working independently according the radiation (red)

On the table below we can see the energy requirements for HVAC conditioning of the different models, distributed in each month of the year. We can see that the most demanding month in terms of cooling is July, with a value higher than 94 MWh for all the three model configurations, being the highest value 101.0 MWh corresponding to the ETD Method.

On terms of heating, the most severe month for conditioning is January, presenting a demand of 9.8 MWh and 9.6 MWh for the Complete and Simplified models respectively. The ETD Method do not consider the effect of internal gains during wintertime, therefore present significantly higher value, of 38.0 MWh for January month.

The overall energy requirement for the entire year surpasses the 400 MWh in cooling load, for the three configurations, which divided by the 6957.5 m^2 of the building surface, represent more than 57.5 kWh/m^2. On this aspect, even if the Dynamic Complete presented higher peaks on the maximum cooling power compared with the ETD model, due to the present of the ISO profiles on the internal gains, it requires less total cooling energy, being 410.7 MWh compared to the 426.4 MWh of the ETD.

In terms of cooling, the decision of not considering the internal gains during the months of November to April according to the ETD Methodology, implied an increase in the output of energy requirement of more than 5 times, being 156.2 MWh for the ETD, compared by the two models that considered them, that gave a result of 29.4MWh and 28.7MWh, being a bit less for the Simplified one, which receives higher solar radiation due to the absence of adjacent buildings.

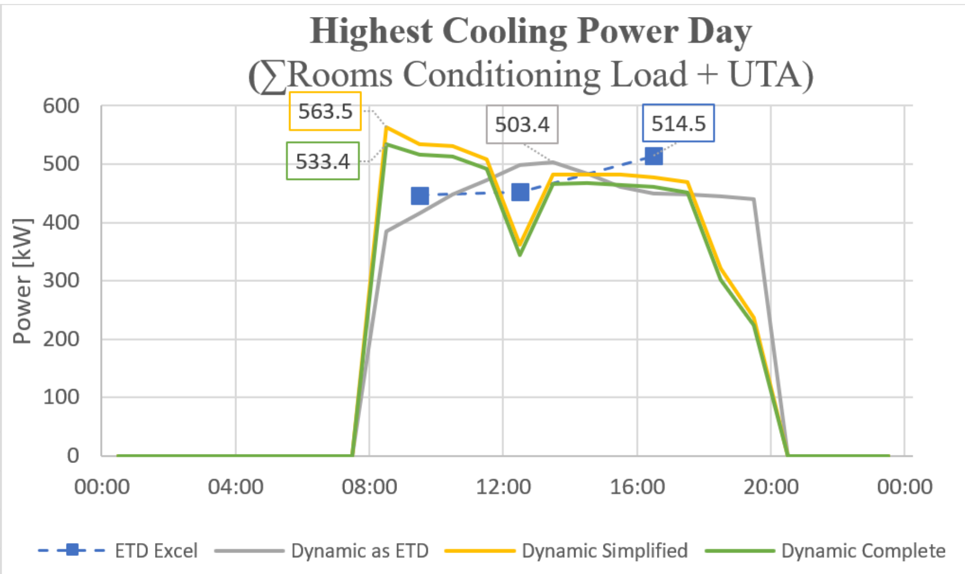
	Dynamic Complete		Dynamic Simplified		ETD Method	
Date	**Heating coils total load (MWh)**	**Cooling coils total load (MWh)**	**Heating coils total load (MWh)**	**Cooling coils total load (MWh)**	**Heating coils total load (MWh)**	**Cooling coils total load (MWh)**
Jan 01-31	9.8	0.0	9.6	0.0	38.0	0.0
Feb 01-28	5.9	0.0	5.5	0.0	30.6	0.0
Mar 01-31	4.1	1.1	4.1	2.2	26.0	0.1
Apr 01-30	0.7	12.2	0.7	13.4	7.4	11.3
May 01-31	0.0	37.2	0.0	39.6	0.0	42.4
Jun 01-30	0.0	65.2	0.0	68.4	0.0	71.4
Jul 01-31	0.0	94.6	0.0	97.9	0.0	101.0
Aug 01-31	0.0	93.8	0.0	97.6	0.0	100.2
Sep 01-30	0.0	67.1	0.0	70.5	0.0	73.9
Oct 01-31	0.0	33.5	0.0	36.5	0.1	24.7
Nov 01-30	1.7	5.8	1.7	7.1	18.7	1.3
Dec 01-31	7.1	0.1	7.1	0.1	35.4	0.1
Summed total	29.4	410.7	28.7	433.2	156.2	426.4

3. Comparison between methods and models, on the peak power.

3.1. Peak Cooling Power:

After having analysed the global year operation of the HVAC for the three different model configurations created, a further analysis was performed, only considering the days with the highest peak power of every model, in order to analyse and compare them individually, since this value is the main parameter to consider on the pre-sizing of an HVAC system. They were also compared with the results obtained using the Effective Temperature Difference Method (ETD) that is usually implemented on the Italian industry for this specific task, method performed in this case by engineers from Lombardini 22, using an Excel file with the parameters and information of the building of analysis, method explained on the *First Chapter.*

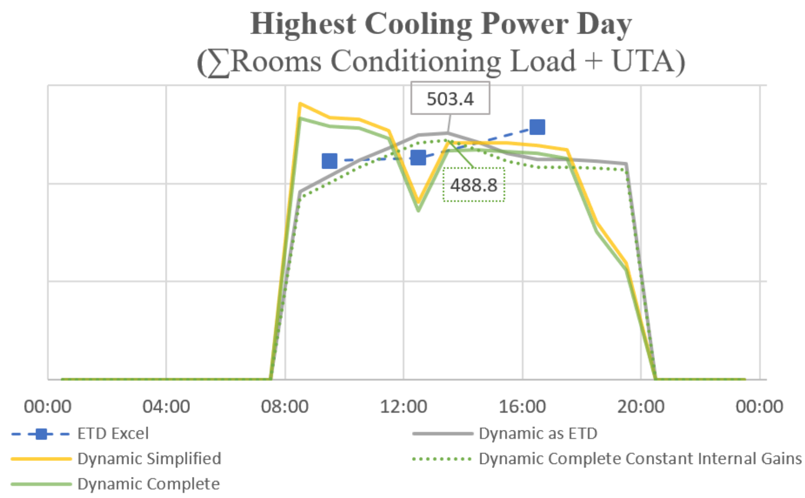
On the cooling peak power, the maximum values of the three model configurations are not so distant from the 514.5kW of maximum power calculated using the ETD. The Simplified model is the less similar one, with a difference of 9%. This difference exists mainly due to the remarkable peak of power in the early morning on the models considering the ISO profiles.



Picture 2.30 – Highest Cooling Power Day for the three models adding the calculated using the ETD Excel

For the Dynamic Simplified model this peak corresponds to 563.5 kW of cooling power needed on the 3rd of August, while 533.4kW for the Dynamic Complete on the same day, both at 8:30 in the early morning. This can be explained as mentioned before, because both models consider a presence of 25% of the appliances load during the whole night, as stated in the ISO normative, creating the accumulation of heat that derives in this initial peak on the next morning, however, later the power required by the HVAC is reduced, even to lower levels than the Model as ETD and the ETD Excel.

In order to verify this hypothesis, an extra simulation was performed with the same Dynamic Complete Model, but without any profile on its internal gains, just the total value from 8h to 20h and 0kW for the rest of the hours, as it was conceived for the Model as ETD. It is shown below and confirms that the peak at 8:30h disappears if the variation on the internal loads proposed by the ISO is neglected, specifically the one referring to the appliances, that leaves a remaining load during the night. Now the peak of the Dynamic Complete is 488.8kW, following the same shape of the "Dynamic as ETD" model, on its peak day 17th of August having 503.4 kW as its peak. The new Dynamic Complete one is lower, explained by the shading created for the adjacent buildings, included on this last more complete one.

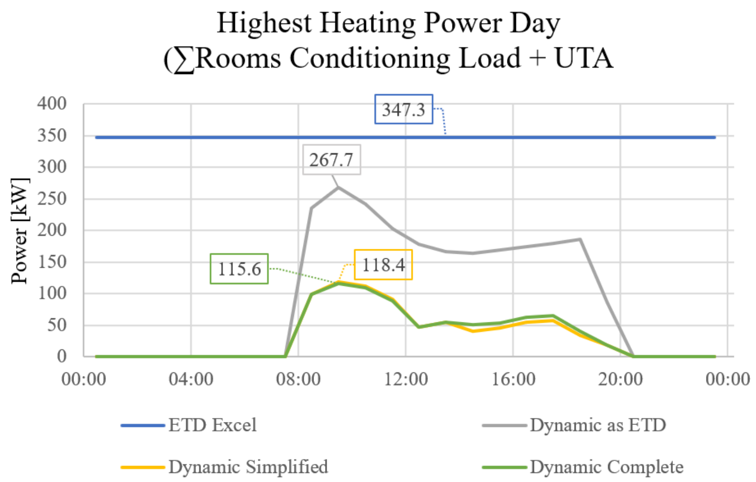


Picture 2.31 – Graph including the Dynamic Complete Model without the internal gains ISO profile on the internal gains

3.2. Peak Heating Power:

The same task was performed for the most demanding days of each model in terms of heating. The results are less homogeneous by far, due to the aspect that the ETD method considerations, applied on both one model and the Excel, do not consider the internal gains during winter period.

The three model configurations present their peak power during the 5th of January but with different results. 267.7kW correspond to the "Dynamic as ETD" model while the Dynamic Simplified and Dynamic Complete are more than half below that, with 118.4kW and 115.6kW respectively.



Picture 2.32 – Highest Heating Power Day for the three models adding the calculated using the ETD Excel (blue line). The difference between the Dynamic Simplified (yellow) and Dynamic Complete (Green) with the Dynamic as ETD (gray) and ETD (blue) is explained mainly by the absence of internal gains on the last two.

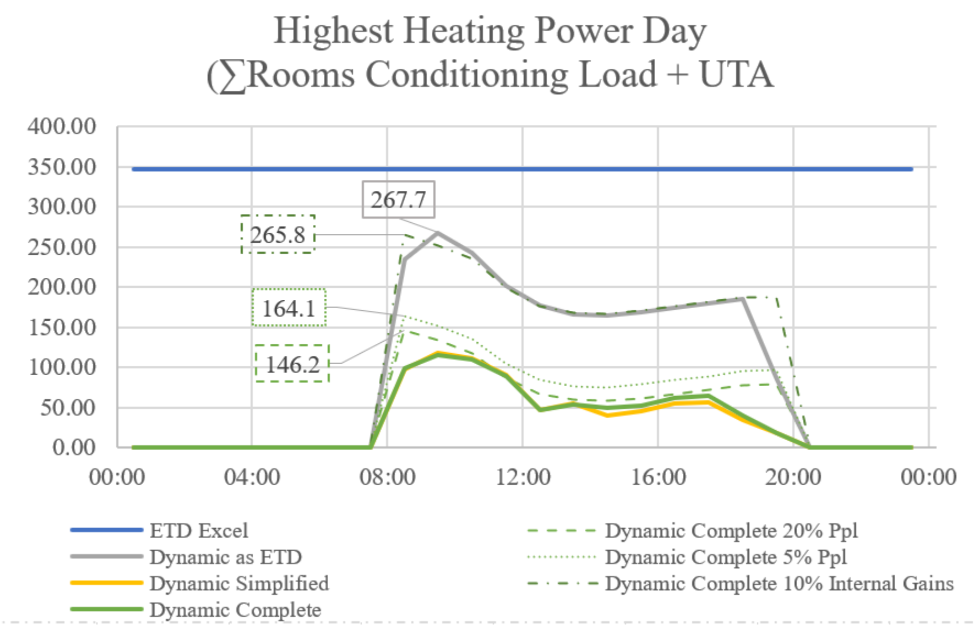
The ETD methodology is trying to simulate the worst-case scenario, in order to define a Power plant able to maintain the determined setpoints of comfort during the hardest conditions. This is performed not only taking a low exterior winter design temperature but also neglecting the impact of the internal and solar gains in reducing the heating needs as stated by the UNI-EN-12831*"Metodo di calcolo del carico termico di proggeto"*.

This decision is taken due to the reason that these contributions are not constantly present (solar radiation, lights, occupants, machines, etc) and the method prefers to maintain a conservative approach.

In order to analyse some possible variations on these internal loads and how is their impact on the heating peak power, some extra simulations were performed modifying the percentage of people and total internal gains, while also thinking the scenarios in real life that the loads could behave in this way.

The absence of a high percentage of the people gain in an office building, as the case of study, could be due to the possibility of smart working job. In modern day life, especially during this covid situation, every day is more probable that workers see the office space as a benefit and not as an obligation, being them the ones that decide which days go to this workspace and when to work from home.

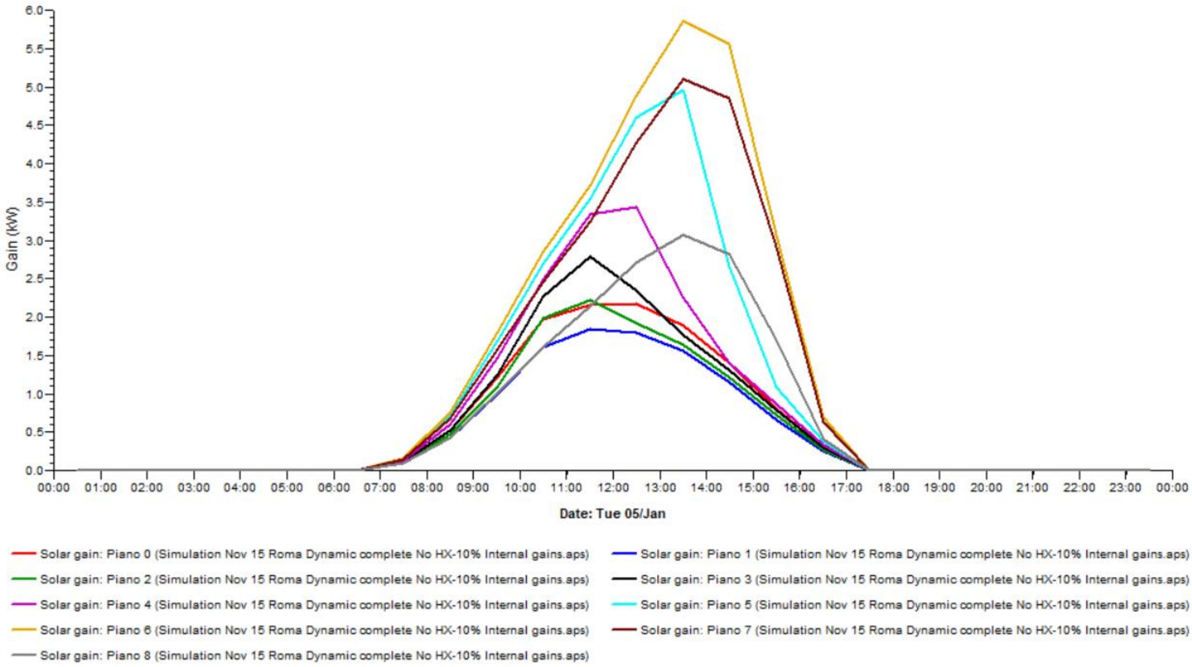
Therefore, is not illogical to think that during a really cold winter day, also with a presence of a heavy rain or snow, most of the workers from the company located in the building of analysis, decide to work from home and don't go to the office (if it is possible for them to do so). As a consequence, the internal gains, due to the reduction of the people and subsequently reduction also on the use of lightning and equipment required by them, will drop heavily, producing an increment in the heating power that the thermal plant need to produce for the remaining people that indeed decided to work at the office during that day, since the comfortable stated conditions inside the building, need to be followed no matter how much percentage of people are present inside the space.



Picture 2.33 – Highest Heating Power Day modifying the internal gains on the Dynamic Complete model

As we see on the graph above, higher the reduction on the internal gains, more similar the results of the Dynamic Complete model get compared to the ETD one. Presenting almost the same peak value of 265.8kW when considering a reduction of 90% on the gains. A reduction on the people gain from 100% to 5% represent an increase in about 50kW of the heating peak power, but still present a value far from the ETD considerations since they represent 27% of the total internal gains with 5.6W/m^2, while the equipment load has a bigger impact due to their 49% of the total with 10W/m^2 (values for this specific project), however, we could infer that both type of gains need to be correlated, since less people inside the office space means less computers or printers used by them, reducing also the equipment gains in the case of considering less people.

Moving on, there is still a difference between the dynamic model considering less or no internal gains, and the static ETD method performed in excel, 265.8 kW of the Dynamic Complete model with 10% of the internal gains against 347.3kW of the ETD method performed by the mechanical engineers. There are two possible causes of this difference, from one side: the solar radiation, still present on every model, as it is included on the EPW file used by the IES-VE software calculations, while it is not considered on the static method for the winter analysis, as seen on *Chapter 1*.



Picture 2.34 – Solar Gain on different floors during the day of the heating peak (5th of January).
Values go from 9kW (1.86W/m^2) at 9h to 28kW(4W/m^2) at 13:30h, considering the combination of the several floors.

The other possible reason of this difference is the simplified approach used in the calculation of the ventilation load performed in the Carrier ETD method, during the preliminary phase. It is considered an initial load of 10W for each m^3/h of ventilation supplied to the internal space, which added to conduction load leaving (or entering, in summer) through the building envelope, as calculated as in the *Chapter 1*, states the final heating load.

For the 666 people distributed on the nine floors of the building of analysis (11.24m^2/person), 26370 m^3/h of air need to be supplied (39.6m^3/h by person ≈ 11 liters/s), representing 263.70kW of energy considered on the preliminary phase. This 10W comes from the approximation of the following equation of the UNI-EN-12831 *Chapter 7.2- Dispersione termica di Progetto per ventilazione.*

$$\Phi_{v,i} = H_{v,i} * (\theta_{int,i} - \theta_e)$$

With:

- $\phi_{v,i}$ as design heat loss through ventilation for a heated space (i) in Watts.
- $H_{v,i}$ as design heat loss coefficient for ventilation in W/K.
- $\theta_{int,i}$ as design internal temperature of the heated space (i) in ºC.
- θ_e as design exterior temperature in ºC.

While the design heat loss coefficient for ventilation $H_{v,i}$ of a heated space (i) is calculated:

$$H_{v,i} = \dot{V}_i * \mathrm{p} * C_p$$

With:

- $\dot{V}_i$ = air flow rate of the heated space in (m^3/s).
- p = air density at $\theta_{int,i}$ in kg/m^3.
- C_p= specific thermal capacity of the air at $\theta_{int,i}$ in kJ/kg*K.

Assuming constant values of p and C_p the equation is reduced to:

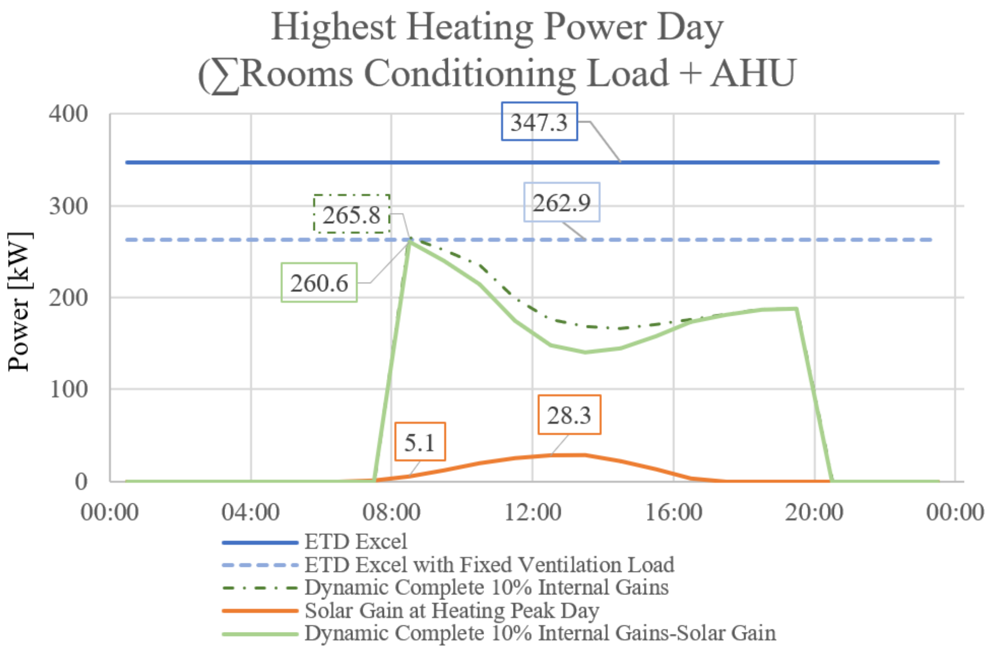
$$H_{v,i} = 0.34 * \dot{V}_i$$

With $\dot{V}_i$ now expressed in m^3/h.

Having 20ºC as design internal temperature $\theta_{int,i}$ and 0ºC as design exterior temperature θ_e for the building in Rome, according to the previously mentioned equation we would have a design heat loss through ventilation equivalent to 6.8W for each m^3/h of air supplied to the building:

$$\phi_{v,i} = H_{v,i} * (\theta_{int,i} - \theta_e) = 0.34 * \dot{V}_i * (\theta_{int,i} - \theta_e)$$
$$= 0.34 * \dot{V}_i * (20ºC - 0ºC) = 6.8 * \dot{V}_i$$

Considering the 26 370 m^3/h of air supplied, the corresponding specific design heat loss through ventilation would be 179 316 W, which is 84.38kW less than the initial approximation. Reducing then the initial 347.3kW of estimated peak heating power of the ETD method in 84.38kW of the difference found, we would have 262.92kW and subtracting the 5.13kW of solar radiation at 8:30h (time of the heating peak) that the ETD method is not considering, to the 265.8kW calculated on the Dynamic Complete model with 10% of the internal gains, there would be difference of only 2.25kW between both methods, 260.67kW of the Dynamic Complete vs 262.92kW of the ETD fixing the ventilation load.



Picture 2.35 – Highest Heating Power Day showing the new ventilation load on the ETD method, and the solar gains during the same day of analysis.

On the graph above with the results already discussed it is seen that both the Dynamic model on IES-VE and the ETD method could lead to the same results, if considering the same conditions. Decreasing totally the internal gains on the Dynamic Complete Model would lead us to higher peak power (now there is still 10% of the internal gains), but since the ETD method do not consider the surrounding buildings, the solar gain would also be higher if we follow the same approach, countering the increase on the heating gains.

4. Conclusion

As it was covered on the previous chapters, the Dynamic modelling can represent a remarkable tool in the HVAC plant pre-sizing. The initial different results on the models compared with the Effective Temperature Difference method (ETD) depend only on the difference in the considerations taken, especially the ones related to the internal gains. During summer period the ETD does not consider the variations on the internal gains during the day as suggested by the ISO normative, neither the shading effect of the surrounding buildings, while during winter season does not consider any solar or internal gain that could contribute to decrease the heating power of the plant system. In other words, the ETD method prefers to maintain a conservative approach in order to have a security margin, considering the highest possible conditioning loads in any situation.

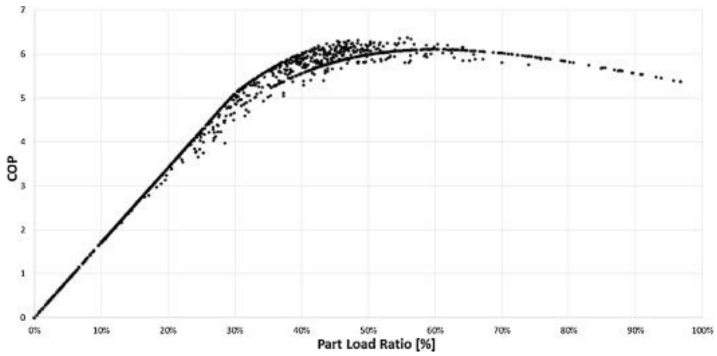
Initially this idea seems logical in the context of prioritizing the comfort of the occupants, but it could also lead to the over dimensioning of the HVAC systems, as the estimation of the maximum heating power required and consequently installed in the buildings. The conditions in real life of complete absence of any heat gain during winter, either by the sun or the ones generated at the interior of the spaces, are difficult to exist, and the installation of HVACs with 2 or even higher capacity that the one actually needed, could lead in the consumption of more energy, since the conditioning equipments will work in less efficiency levels, according to the partial load curves of the machines.

CARICHI PARZIALI IN RISCALDAMENTO

Carico	%	100,0	90,0	80,0	70,0	60,0	50,0	40,0	30,0	20,0	10,0
Temp. aria esterna	°C	-7,0	-7,0	-7,0	-7,0	-7,0	-7,0	-7,0	-7,0	-7,0	-7,0
Carico termico	kWh	327	294	262	229	196	164	131	98	65	33
Potenza assorbita totale	kW	139,4	121,5	104,3	87,70	72,00	59,20	47,90	36,40	24,70	13,50
Temp. ingresso condensatore	°C	40,00	40,50	41,00	41,50	42,00	42,50	43,00	43,50	44,00	44,07
Temp. uscita condensatore	°C	45,00	45,00	45,00	45,00	45,00	45,00	45,00	45,00	45,00	45,00
Portata fluido condensatore	l/s	15,78	15,78	15,78	15,78	15,78	15,78	15,78	15,78	15,78	15,78
COP	kW/kW	2,350	2,420	2,510	2,610	2,720	2,760	2,730	2,700	2,640	2,420

Picture 2.37. Data Sheet of a heat pump NX2-Q-G06 from Mitsubishi. Usually installed in Italian buildings. It is highlighted the variation on the energy efficiency of the system (COP) according to the supplied heat.

The same situation can happen due to the not consideration of the surrounding buildings in the calculation of the maximum cooling power. This was not the case of the building of analysis since it is the tallest one on its area, and the difference between the Dynamic Complete model that considered the building context and ETD method calculation was not relevant, but in a different context where its needed an HVAC sizing of a small or medium high building surrounded by high-rises, the difference in considering or not the surroundings could lead into a decision of installing a chiller plant 2 or 3 times bigger than needed and the subsequently working condition in lower EER.



Picture 2.36 Part Load Ratio vs COP – from "Detailed analysis on part load ratio characteristics and cooling energy saving of chiller staging in an office building", by Byeong MoSeo and Kwang HoLee Hanbat- National University, Daejeon, South Korea

The dynamic energy modelling for buildings applied on pre-sizing or sizing the HVAC systems leaves the engineer the possibility of decision, in whether or not, and in which proportion, overestimate the required peak powers, since he/she is able to control the variables that determine directly on the final results. The decision on considering the internal gains and their variation during the day, the solar gains and shading control, etc..and the corresponded values that these variables have, distinguish the dynamic energy modelling from the static/stationary methodologies as ETD that are more constrained to the stated worst conditions and don't have an option "in between", where the engineers could control on which approximately efficiency conditions the HVAC will work, leading to higher energy savings.