POLITECNICO DI MILANO

School of Architecture, Urban Planning and Construction Engineering
Master of Science in Building and Architectural Engineering

HVAC DEFINITION AND DYNAMIC SIMULATIONS FOR A SUPERMARKET IN EMILIA ROMAGNA, ACCORDING TO DGR 967/2015

Supervisor:

Prof. Rossano Scoccia

Master dissertation of:

Tommaso Barbieri, Matr.883473

Simone Stucchi, Matr.874442

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Abstract

With the growing interest on climate changes due to global warming, the construction sector plays a key role, in fact it is responsible for 40% of total energy consumption and the production of 36% of greenhouse gases in Europe. In recent years, many states and regions within the European Union have adopted environmental policies to combat climate change. Among these regions there is also Emilia Romagna, which through the DGR 967/2015, tries to give its contribution to the reduction of polluting gases. Due to this, the plants must be completely redesigned to comply with the new regulations. This thesis deals with the design, modeling and dynamic simulation of an all air conditioning system for a new supermarket, located in Emilia Romagna, and therefore in compliance with the new regulations in force in the area. Here are proposed four different types of plant, considered compliant with a supermarket and the new regulations, all modelled through the software TRNSYS. The proposals that respect the minimum regulation (50% of energy from renewable sources) are: 1) the use of a plant composed of a AHU combined with a chiller and a heat pump with on-site generation made by a field of photovoltaic panels that use a renewable percentage of 50.58%. 2) a plant with a AHU combined with a chiller and a biogas CHP (with a backup heat pump) that reaches a percentage of renewables of 61.34. 3) a plant with a AHU DEC combined with a chiller and a biogas CHP (with a backup heat pump) that reaches a renewable percentage of 67.56. 4) a plant with a AHU DEC combined with a chiller and a heat pump with on-site generation entrusted to a field of photovoltaic panels and solar thermal systems that reaches a renewable percentage of 63.84.

Sintesi

Con il crescente interessamento alla tematica dei cambiamenti climatici dovuti al surriscaldamento globale il settore delle costruzioni gioca un ruolo fondamentale, infatti è responsabile del 40% dei consumi totali di energia e della produzione del 36% dei gas serra presenti in Europa. Negli ultimi anni molti stati e regioni all'interno dell'unione europea hanno adottato politiche ambientali per combattere i cambiamenti climatici. Tra queste regioni vi è anche l'Emilia Romagna, che attraverso il DGR 967/2015, cerca di dare il suo contributo alla diminuzione dei gas inquinanti. Alla luce di ciò gli impianti devono essere completamente ripensati per sottostare alle nuove regolamentazioni. Questa tesi affronta la progettazione, modellazione e simulazione dinamica di un impianto di climatizzazione a tutt'aria per un supermercato di nuova costruzione, situato in Emilia Romagna, e dunque conforme alle nuove normative vigenti sul territorio. Vengono qui proposte quattro diverse tipologie di impianto, ritenute conformi ad un supermercato e alle nuove normative, tutte modellate tramite il software il calcolo energetico TRNSYS. Le proposte che rispettano il minimo da normativa (50% di energia da fonti rinnovabili) sono: 1) l'uso di un impianto composto da un UTA abbinato ad una macchina frigorifera e ad una pompa di calore con la generazione in sito fatta da un campo di pannelli fotovoltaici che usa una percentuale di rinnovabile del 50.58%. 2) un impianto con un UTA abbinato ad una macchina frigorifera e un CHPe a biogas (con una pompa di calore di backup) che raggiunge una percentuale di rinnovabili del 61.34. 3) un impianto con un UTA DEC abbinato ad una macchina frigorifera e un CHPe a biogas (con una pompa di calore di backup) che raggiunge una percentuale di rinnovabili del 67.56. 4) un impianto con un UTA DEC abbinato ad una macchina frigorifera e una pompa di calore con la generazione in sito affidata ad un campo di pannelli fotovoltaici e dei solari termici che raggiunge una percentuale di rinnovabile del 63.84.

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I. INTRODUCTION

Construction field nowadays is one of the global warming biggest responsible (almost the 30% of the total energy consumption), so the study of Net Zero Energy Buildings (NZEBs) is fundamental, because they are the main strategy to reduce the building demands and the CO_2 emissions.

Buildings and building systems have a long lifetime which generates opportunities for reduction in energy consumption, as in greenhouse gases emission. With a proper design and the using best available technological systems it is possible to achieve significant energy and CO_2 emission reduction. The most important challenge is to reduce the carbon footprint in buildings without influencing the internal environmental quality in terms of thermal comfort and carbon dioxide content in the air.

On 2010 a Recast of the Energy Performance of Buildings Directive (EPBD) was adopted from the European Parliament: The Directive 2010/31/EU is focused on energy efficiency of buildings that requires the achievement of high energy standards for new public buildings from December 31th 2018 and, for all new constructions, from December 31th 2020. This obligation is included in the introduction of the concept of "almost zero energy buildings" (Nearly Zero Energy Building - nZEB), defined as a building with high energy performance, whose needs, very close to zero, should be energy-covered from renewable sources.

According to EPBD principles, In Italy the “legge 90/2013” [10] imposes limits on building energy consumption in the national territory and fixes the carbon dioxide emission reduction. Following the national code, regions enacted his own code about building energy efficiency. Recently, In Emilia Romagna, the region where the project of this thesis is located in, the DGR 967/2015 “Requisiti minimi di prestazione energetica degli edifici” [1] has been adopted. This standard introduced new energy standards for private and public building in the regional territory, this involved that all the new construction must be studied to reach new high energy standard. In the next chapter the national and regional code will be analysed in detail, focusing on the new standards that must be followed in this project.

In this thesis the main concept of usage of renewable energy for commercial plants will be applied to a real case study: a supermarket placed in Emilia Romagna region in Italy, trying to find out the best solution in terms of thermal energy needs, internal comfort and costs. Finally, the possible systems solutions for a higher performance and a more energetic optimized supermarket will be suggested.

II. ITALIAN REGULATION

The European Union officially adopted the 20-20-20 Renewable Energy Directive on December 2009 (Directive 2009/28/EU) setting climate change reduction goals for the next decade. The targets call for a 20% reduction in greenhouse gas (GHG) emissions by 2020 compared with 1990 levels, a 20% cut in energy consumption through improved energy efficiency by 2020 and a 20 percent increase in the use of renewable energy by 2020. In 2005 renewable energies from hydro-power, solar, wind, biomass or geothermal sources accounted for less than 7% of the EU's total energy consumption. To achieve the 20% target, the new directive lays down mandatory national targets to be achieved by the member states through promoting the use of renewable energy in the electricity, transport, heating and cooling sectors.

Seeing this, is critical to understand what are the total consumptions for heating and cooling in a project. Moreover, has to be taken into account also another feature: the Energy Performance of Buildings Directive (EPBD, 2010/31/EU) [10] introduced the definition of nZEB as a building with very high energy performance where the nearly zero or very low amount of energy required should be extensively covered by renewable sources produced on-site or nearby. The EPBD foresees that after 31 December 2020, all new buildings will be nZEBs, while for public buildings the deadline is set for 31 December 2018.

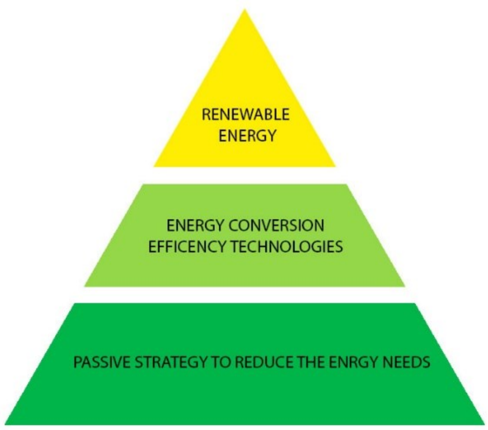


Figure II-1: Energy saving strategy

2.1 New standards

Considering the region where project is located (Emilia Romagna, Italy) and the DGR 967/2015 "Requisiti minimi di prestazione energetica degli edifici" [1] all the private buildings must be a nZEB anticipating of about 2 years the European disposals. In the following picture can be seen the different standards, from the European one to the regional one; standards that has to be followed during the design of every type of building.

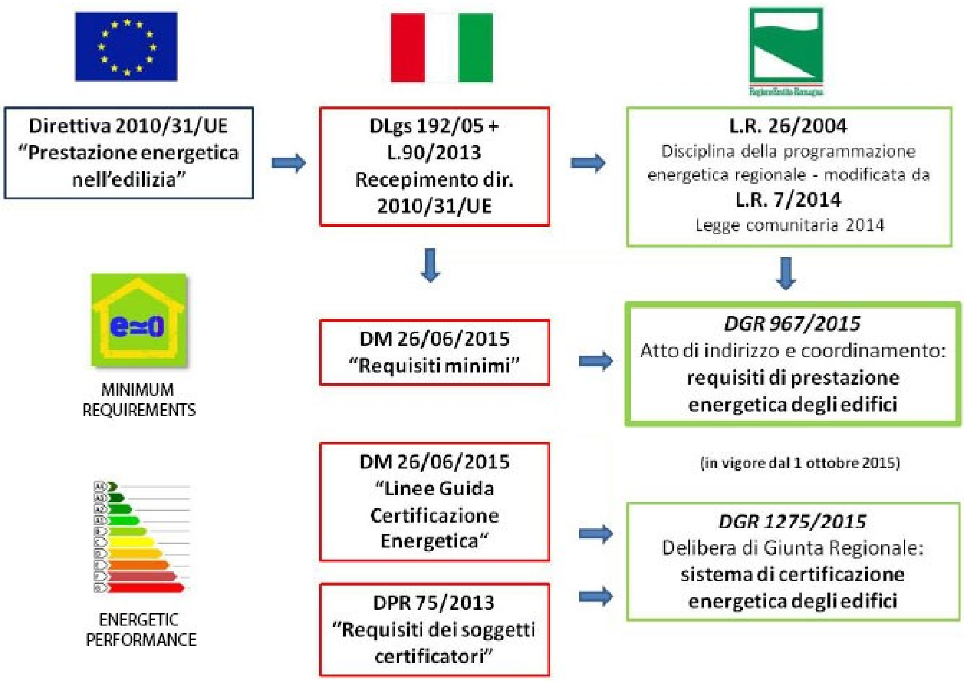


Figure II-2 : Italian regulation summary

It is possible to summarize the main news from the new legislation with the following scheme:

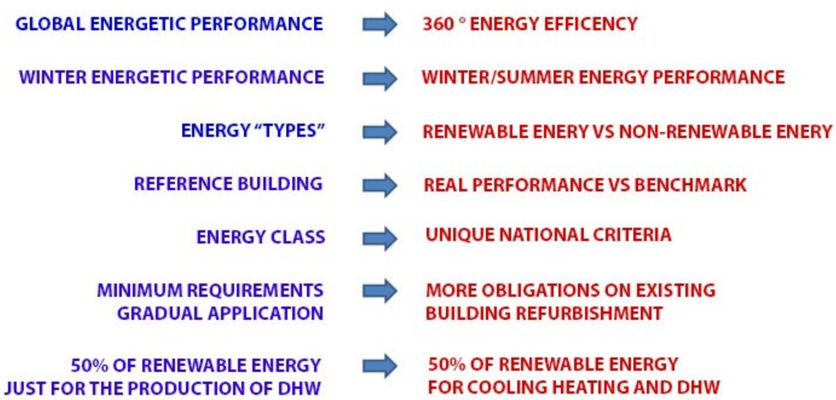


Figure II-3 : Italian standards changes

The main parameter that has to be calculated is the global energy performance (EP_{gl}) [1]. It describes the quantity of primary energy consumed to satisfy a standard use of the building, for all the considered services. The global energy performance is the sum of all the partial indices:

$$EP_{gl} = EP_H + EP_W + EP_V + EP_C \ (+ EP_L + EP_T)$$

Equation II-1: Global energy performance

Where:
EP_{gl} *-> global energy performance*
EP_h *-> heating energy performance*
EP_w *-> winter energy performance*
EP_v *-> ventilation energy performance*
EP_c *-> domestic hot water energy performance*
EP_l *-> lighting energy performance*
EP_t *-> transport energy performance (lift and other movable machines)*

Primary energy is an energy that has not been subjected to any conversion or transformation process. It includes non-renewable energy and renewable energy. If both are taken into account, it can be called total primary energy. For buildings, it is the energy used to produce the energy delivered to the building. It is calculated from the delivered and exported amounts of energy carriers, using conversion factors that are unique for every nation. For Italy are the following:

"Nell'ambito delle metodologie di calcolo di cui alla DGR 967/2015 per la verifica dei requisiti minimi, e alla DGR 1275/2015 per l'attestazione della prestazione energetica degli edifici e l'emissione del relativo attestato, si applicano – come esplicitamente previsto dalle norme citate – i seguenti fattori di conversione dell'energia fornita per il funzionamento degli impianti per fonte / vettore energetico, in energia primaria rinnovabile ($E_{P,ren}$), non rinnovabile ($E_{P,nren}$) e totale ($E_{P,gl}$)."

Energy vector	$f_{p,nren}$	$f_{p,ren}$	$f_{p,tot}$
Natural gas	1,05	0	1,05
GPL	1,05	0	1,05
Diesel oil and fuel oil	1,07	0	1,07
Coal	1,10	0	1,10
Solid biomass	0,2	0,8	1,00
Liquid or gaseous biomass	0,4	0,6	1,00
Electric energy from the net	1,95	0,47	2,42
District heating	1,5	0	1,5
Solid urban waste	0,2	0,2	0,4
District cooling	0,5	0	0,5
Electric energy from photovoltaic panel	0	1,00	1,00
Thermal energy from solar panel	0	1,00	1,00
Thermal energy from outside environment-free cooling	0	1,00	1,00
Thermal energy from outside environment – heat pump	0	1,00	1,00

Table II-1 : Energy vectors renewable percentage

However, there is not only energy certification to keep into account. In addition to the EPBD directives [10], the legislation provided other directives with the aim of intervening in the subject with the widest possible range of action and covering the whole world of energy efficiency.

The Directive 2009/28 / EU "Promozione dell’uso dell’energia da fonti rinnovabili" implemented in Italy through D.lgs n. 28/2011 [11] imposes the use of the latter in order to achieve the minimum levels of use of renewable energy set by the European community for 2020. The directive enters fully into the energy efficiency of buildings as it imposes, with percentages gradually increasing, the use of renewable energy in new buildings or undergoing major renovation. In particular, it is mandatory to install systems that guarantee simultaneously:

- The coverage of 50% of the consumption of DHW (domestic hot water) from renewable sources
- The coverage through renewable sources of global annual consumption for heating, DHW and cooling with the following percentages:
    - 20% when the request for the relevant building title is presented from 1 May 2012 to 31 December 2013;

- 35% when the request for the relevant building title is presented from 1 January 2014 to 31 December 2016;
- 50% when the request for the relevant building title is presented from 1 January 2017

It is also mandatory, for new buildings and buildings subject to significant renovation, to install RES (renewable energy systems) plants with a power P equal to (1 / K) * S that produce electricity, where S is the surface in plan of the building at ground level, while K is a coefficient that assumes the following values:

- K = 80 when the request for the relevant building title is presented from 1 May 2012 to 31 December 2013;
- K = 65 when the request for the relevant building title is presented from 1 January 2014 to 31 December 2016;
- K = 50 when the request for the relevant building title is presented from 1 January 2017.

2.2 Technical aspects

2.2.1 Building envelope

It is evident how the new legislation gives a not indifferent push towards the construction or renovation of buildings with high energy performance, with increasingly isolated casings due to the obligation to respect much more severe transmission values of opaque and transparent surfaces than previous ones. In the new standards (DGR 967/2015) [1] the values that must be respected, for the different type of partitions, are the following:

"Trasmittanza termica U delle strutture opache verticali, verso l'esterno, gli ambienti non climatizzati o contro terra:"

Zona climatica	U (W/m²K)	
	2015	2017/2019
D	0,34	0,29
E	0,30	0,26
F	0,28	0,24

Table II-2 : Vertical closure minimum thermal transmittance

"Trasmittanza termica U delle strutture opache orizzontali o inclinate di copertura, verso l'esterno e gli ambienti non climatizzati:"

Zona climatica	U (W/m²K)	
	2015	2017/2019
D	0,30	0,26
E	0,25	0,22
F	0,23	0,20

Table II-3 : Roof minimum thermal transmittance

"Trasmittanza termica U delle strutture opache orizzontali di pavimento verso l'esterno, gli ambienti non climatizzati o contro terra:"

Zona climatica	U (W/m²K)	
	2015	2017/2019
D	0,32	0,29
E	0,30	0,26
F	0,28	0,24

Table II-4 : Horizontal closure minimum thermal transmittance

"Trasmittanza termica U delle chiusure tecniche trasparenti e opache e dei cassonetti, comprensivi di infissi, verso l'esterno e gli ambienti non climatizzati:"

Zona climatica	U (W/m²K)	
	2015	2017/2019
D	2,00	1,80
E	1,80	1,40
F	1,50	1,10

Table II-5 : Transparent closure minimum thermal transmittance

"Valore del fattore di trasmissione solare $g_{gf,sh}$ per componenti finestrati con orientamento da Est a Ovest passando per Sud."

Zona climatica	$g_{gl.sh}$	
	2015	2017/2019
Tutte le zone	0,35	0,35

Table II-6 : Glass minimum solar transmittance

The most important thing is to understand what are the parameters that the standard says have to be calculated.

The global and partial energy performance requirements are verified though a reference building. This means an identical building in terms of geometry, orientation, territorial location, intended use and boundary situation and having a predetermined thermal characteristics and energy parameters. In the Table II-7 [1] are reported the energy performance indices (expressed in kWh/m^2) and the efficiency parameters that have to be computed.

INDICI E PARAMETRI	*DESCRIZIONE*	*OBBLIGO VERIFICA*
$EP_{H,nd}$	**indice di prestazione termica utile per riscaldamento;**	**SI**
η_H [-]	**efficienza media stagionale dell'impianto di climatizzazione invernale;**	**SI**
$EP_{H,tot}$	indice di prestazione energetica per la climatizzazione invernale espresso in energia primaria totale (indice "tot")	**NO**
$EP_{H,nren}$	indice di prestazione energetica per la climatizzazione invernale espresso in energia primaria non rinnovabile (indice "nren")	**NO**
$EP_{W,nd}$	indice di prestazione termica utile per la produzione di acqua calda sanitaria nell'edificio;	**NO**
η_W	**efficienza media stagionale dell'impianto di produzione dell'acqua calda sanitaria;**	**SI**
$EP_{W,tot}$	indice di prestazione energetica per la produzione dell'acqua calda sanitaria espresso in energia primaria totale (indice "tot")	**NO**
$EP_{W,nren}$	indice di prestazione energetica per la produzione dell'acqua calda sanitaria espresso in energia primaria non rinnovabile (indice "nren")	**NO**
$EP_{V,tot}$	indice di prestazione energetica per la ventilazione espresso in energia primaria totale (indice "tot")	**NO**
$EP_{V,nren}$	indice di prestazione energetica per la ventilazione espresso in energia primaria non rinnovabile (indice "nren")	**NO**
$EP_{C,nd}$	**indice di prestazione termica utile per il raffrescamento;**	**SI**
η_C	**efficienza media stagionale dell'impianto di climatizzazione estiva (compreso l'eventuale controllo dell'umidità);**	**SI**
$EP_{C,tot}$	indice di prestazione energetica per la climatizzazione estiva (compreso l'eventuale controllo dell'umidità) espresso in energia primaria totale (indice "tot")	**NO**
$EP_{C,nren}$	indice di prestazione energetica per la climatizzazione estiva (compreso l'eventuale controllo dell'umidità) espresso in energia primaria non rinnovabile (indice "nren")	**NO**
$EP_{L,tot}$ (1)	indice di prestazione energetica per l'illuminazione artificiale, espresso in energia primaria rinnovabile totale (indice "tot")	**NO**
$EP_{L,nren}$ (1)	indice di prestazione energetica per l'illuminazione artificiale, espresso in energia primaria non rinnovabile (indice "nren")	**NO**
$EP_{T,tot}$ (1)	indice di prestazione energetica del servizio per il trasporto di persone e cose (impianti ascensori, marciapiedi e scale mobili), espresso in energia primaria rinnovabile totale (indice "tot")	**NO**
$EP_{T,nren}$ (1)	indice di prestazione energetica del servizio per il trasporto di persone e cose (impianti ascensori, marciapiedi e scale mobili), espresso in energia primaria non rinnovabile (indice "nren")	**NO**
$EP_{gl,tot} = EP_{H,tot} + EP_{W,tot} + EP_{V,tot} + EP_{C,tot} + EP_{L,tot} + EP_{T,tot}$	**indice di prestazione energetica globale dell'edificio, espresso in energia primaria totale (indice "tot")**	**SI**
$EP_{gl,nren} = EP_{H,nren} + EP_{W,nren} + EP_{V,nren} + EP_{C,nren} + EP_{L,nren} + EP_{T,nren}$	indice di prestazione energetica globale dell'edificio, espresso in energia primaria non rinnovabile (indice "nren")	**NO**

Table II-7 : Energy efficiencies parameters

2.2.2 Plants

As specified by the standard in the chapter A.4 [1] for all the categories of existing buildings, as classified according to the intended use in article 3 of the DP of 26 August 1993 n°412, in case of new installation and renovation of heating systems or replacement of heat generators, the hating systems must comply with the following requirements:

"A.4.1 REQUISITI DEGLI IMPIANTI ALIMENTATI DA BIOMASSE COMBUSTIBILI

1. Nel caso in cui è prevista l'installazione di impianti termici dotati di generatori di calore alimentati da biomasse combustibili, si procede in sede progettuale alla verifica che il generatore di calore rispetti i requisiti seguenti:

a) rispetto dei rendimenti termici utili nominali corrispondenti alle classi minime di cui alle pertinenti norme di prodotto riportate nella seguente tabella:"

Tipologia	**Norma di riferimento**
Caldaie a biomassa	UNI EN 303-5
Caldaie con potenza <50 kW	UNI EN 12809
Stufe a combustibile solido	UNI EN 13240
Apparecchi per il riscaldamento domestico alimentati a pellet di legno	UNI EN 14785
Termocucine	UNI EN 12815
Inserti a combustibile solido	UNI EN 13229
Apparecchi a lento rilascio	UNI EN 15250
Bruciatori a pellet	UNI EN 15270

Table II-8 : Thermal generators reference normative

"A.4.2 REQUISITI DELLE UNITÀ DI MICROCOGENERAZIONE

1. *Nel caso di installazione di impianti di microcogenerazione, il rendimento energetico delle unità di produzione, espresso dall'indice di risparmio di energia primaria PES, calcolato conformemente alla quanto previsto dall'Allegato III del decreto legislativo 8 febbraio 2007, n. 20, e dall'Allegato 7 del presente provvedimento misurato nelle condizioni di esercizio (ovvero alle temperature medie di ritorno di progetto), dal 1 gennaio 2015, deve risultare non inferiore a 0, ad eccezione dei casi indicati alla successiva sezione B punto B.7.4."*

For the purpose of calculating the total energy performance index $EP_{gl,tot}$ in the cases provided for in the standard the contribution of energy from the renewable sources can be considered only on condition that the plants have the following minimum features:

"A.5 REQUISITI MINIMI DEGLI IMPIANTI PER IL RICONOSCIMENTO QUOTA FER

1. *Ai fini del calcolo dell'indice di prestazione energetica globale totale EPgl,tot, nei casi previsti dal presente atto, l'apporto di energia da fonte rinnovabile può essere considerato – con le modalità previste dalla normativa vigente e le specifiche di cui all'Allegato 3 – solo a condizione che i relativi impianti presentino le seguenti caratteristiche minime:*

A.5.1 IMPIANTI A BIOMASSA

1. *Nelle more dell'emanazione dei Regolamenti della Commissione europea in materia, attuativi della Direttiva 2009/124/CE e 2010/30/UE, sono considerati ricadenti fra gli impianti alimentati da fonte rinnovabile gli impianti termici di climatizzazione invernale dotati di generatori di calore alimentati da biomasse combustibili, per i quali siano verificate le condizioni seguenti:*

   a) siano dotati di generatori di calore alimentati a biomasse solidi combustibili con le caratteristiche di cui al precedente requisito A.4.1).

   b) che il valore della trasmittanza termica (U) delle diverse strutture edilizie, opache e trasparenti, che delimitano l'edificio verso l'esterno o verso vani non riscaldati sia inferiore o uguale a quello riportato nelle pertinenti tabelle di cui al successivo requisito D1 – "Controllo delle perdite per trasmissione"
2. *In tali casi, e fino all'emanazione delle norme tecniche di riferimento, per il calcolo dell'indice di prestazione energetica globale totale EPgl,tot, si assume una quota di energia fossile pari all'energia primaria realmente fornita all'impianto moltiplicata per il fattore di conversione in energia primaria previsto nell'Allegato 3.*

A.5.2 POMPE DI CALORE

1. *Ai fini della determinazione dell'indice di prestazione energetica globale totale EPgl,tot, la quantità di energia resa disponibile dalle pompe di calore da considerarsi energia da fonti rinnovabili, ERES, di origine aerotermica,*

geotermica o idrotermica, è calcolata in base ai criteri di cui all'allegato VII della Direttiva 28/2009, applicando la seguente metodologia.

a) Nel caso di pompe di calore elettriche, si considera:

$$SPF = \eta * SCOP = Epdc/Ep,pdc$$

Equation II-2 : Global efficiency factor

dove:

- SPF è il fattore di rendimento definito dall'allegato VII della direttiva 2009/28/CE

- SCOP (Seasonal coefficient of performance) è il fattore di rendimento stagionale medio stimato sulla base del metodo normalizzato

- Epdc è l'energia fornita dalla pompa di calore durante la stagione (kWh/anno) data dalla sommatoria dell'energia fornita dalla pompa di calore per unità di calcolo, nei mesi di riscaldamento

- Ep,pdc è l'energia primaria consumata dalla pompa di calore durante l'intera stagione di riscaldamento (kWh/anno)

- η è il fattore di conversione dell'energia elettrica in energia primaria indicato nella tabella di cui all'Allegato 3 art. 2 comma 3 punto g.

Per i soli impianti a pompa di calore con SPF > 1,15 si procede al computo dell'energia rinnovabile secondo l'equazione:

$$ERES = Epdc * [1 - (1/(SPF))] \text{ (kWh/anno)}$$

Equation II-3: Renewable energy from heat pump

Per impianti per i quali non sia verificata in condizione di esercizio la prestazione SPF > 1,15 non si può effettuare il calcolo di ERES.

B.7.4 CARATTERISTICHE MINIME DELLE UNITÀ DI MICROCOGENERAZIONE

1. *Nei casi di cui ai precedenti punti B.7.1 comma 5 lettera b) e B.7.2, comma 5 lettera b), qualora cioè venga prevista l'installazione nell'edificio o nel complesso edilizio di unità di micro o piccola cogenerazione ad alto rendimento in alternativa rispetto alla installazione di impianti di produzione di energia da FER, tali unità di cogenerazione devono avere le seguenti caratteristiche minime:*

B.7.4.1 POTENZA DELLE UNITÀ DI COGENERAZIONE

1. *Per potenza delle unità di cogenerazione s'intende la potenza nominale effettiva ovvero espressa al netto del consumo degli organi ausiliari interni alla/alle unità costituenti la sezione cogenerativa stessa.*

B.7.4.2 RENDIMENTO ENERGETICO MINIMO DELLE UNITA' DI MICRO-COGENERAZIONE

1. *Il rendimento energetico delle unità di micro-cogenerazione è espresso dall'indice di risparmio di energia primaria PES, come definito dal DM 4 agosto 2011. Ai fini dell'impiego di unità di micro-cogenerazione nell'ambito dei casi di cui ai precedenti punti B.7.1 punto 5 lettera b) e B.7.2, punto 5 lettera b), l'indice di risparmio di energia primaria PES misurato nelle condizioni di esercizio (ovvero alle temperature medie di ritorno di progetto) deve risultare:*

$$PES > 0,20$$

L'indice PES si calcola mediante applicazione della seguente formula:

$$PES = [1 - \frac{1}{\frac{CHPH\eta}{RefH\eta} + \frac{CHPE\eta}{RefE\eta}}]$$

Equation II-4: primary energy saved index

dove:

− PES: indice di risparmio di energia primaria (Primary Energy Saving);

− CHPHh: rendimento termico della produzione mediante cogenerazione, definito come la quantità annua di calore utile (QCG,ter,out,an) divisa per l'energia contenuta nell'intero combustibile di alimentazione impiegato per produrre sia il calore utile che l'energia elettrica da cogenerazione (QCG,p,in,an)

− CHPEh: rendimento elettrico della produzione mediante cogenerazione, definito come energia elettrica netta annua da cogenerazione (QCG,el,out,an) divisa per l'energia contenuta nell'intero combustibile di alimentazione impiegato per produrre sia il calore utile che l'energia elettrica da cogenerazione (QCG,p,in,an)

− Ref Hh: rendimento termico di riferimento, di cui al DM 4 settembre 2011;

− Ref Eh: rendimento elettrico di riferimento, di cui al DM 4 settembre 2011.

2. *Il progettista dovrà inserire nella relazione di cui all'art. 8 comma 2 il calcolo dell'indice PES atteso a preventivo su base annua, per la determinazione del quale:*

− devono essere considerate ed esplicitate le condizioni di esercizio (ovvero le temperature medie di ritorno di progetto) in funzione della tipologia di impianto

− devono essere utilizzate le metodologie di calcolo di cui alla norma UNI TS 11300-4 e relative allegati

− i dati relativi alle curve prestazionali devono essere rilevati secondo norma UNI ISO 3046

− deve essere adottata l'ipotesi di cessione totale in rete dell'energia elettrica prodotta, a meno che non siano resi disponibili i dati relativi alla frazione attesa di autoconsumo dell'energia elettrica cogenerata.

B.7.4.3 RENDIMENTO ENERGETICO MINIMO PER LA COGENERAZIONE E LA PICCOLA COGENERAZIONE

1. *Il rendimento energetico minimo richiesto per le tecnologie di cogenerazione con potenza elettrica ≥ di 50 kW è definito dalle condizioni di rendimento imposte per la CAR (Cogenerazione ad AltoRendimento).*

   Cogenerazione ad alto rendimento: cogenerazione con caratteristiche conformi ai criteri indicate nell'Allegato III del decreto legislativo 8 febbraio 2007 n. 20 e nel decreto ministeriale 4 agosto 2011.

B.7.4.6 LIMITI ALLE EMISSIONI DEGLI INQUINANTI IN ATMOSFERA

1. *Per le tecnologie di cogenerazione con potenza elettrica utile < 50 kWel (micro-cogenerazione) vengono considerati i seguenti limiti per l'emissioni in atmosfera delle sostanze inquinanti:*

   - CO [mg/Nm^3 con 5% O^2] : < 50

   - NOx [mg/Nm^3 con 5% O^2] : < 250
2. *Per le tecnologie di cogenerazione con potenza elettrica utile >50 kWel (piccola cogenerazione e cogenerazione) vengono considerati i seguenti limiti per l'emissioni in atmosfera delle sostanze inquinanti:*

   - CO [mg/MJ fuel con 15% O^2] : < 20

   - NOx [mg/ MJ fuel con 15% O^2] : < 60"

2.2.3 Self-regulation and control system

To save energy and ensure the maximum level of comfort inside the building the DGR 967/2015 [1] suggests the use of some control system:

B.5 ADOZIONE DI SISTEMI DI REGOLAZIONE E CONTROLLO

1. *Gli impianti di climatizzazione invernale devono essere dotati di sistemi per la regolazione automatica della temperatura ambiente nei singoli locali o nelle singole zone termiche al fine di non determinare sovra riscaldamento per effetto degli apporti solari e degli apporti gratuiti interni. Tali sistemi devono essere assistiti da compensazione climatica; la compensazione climatica può essere omessa ove la tecnologia impiantistica preveda sistemi di controllo equivalenti o di maggiore efficienza o qualora non sia tecnicamente realizzabile. Tali differenti impedimenti devono essere debitamente documentati nella relazione tecnica di cui all'art. 8 comma 2 dell'Atto.*
2. *Ad esclusione degli interventi di ampliamento serviti mediante estensione dei sistemi tecnici preesistenti, di cui alla categoria 1, punto iii lett. b) dell'art. 1, deve essere prevista l'installazione di sistemi di misurazione intelligente dell'energia consumata, conformemente a quanto previsto all'articolo 9 del decreto legislativo 4 luglio 2014, n.102.*
3. *Nel caso di edifici di nuova costruzione di cui all'art. 3 comma 2 lett. a) dell'Atto, devono essere adottati sistemi di automazione per il controllo, la regolazione e la gestione delle tecnologie dell'edificio e degli impianti termici (BACS) che garantiscano prestazioni:*

   - pari alla classe B come definita nella Tabella 1 della norma UNI EN 15232 e successive modifiche o norma equivalente, per gli edifici ad uso non residenziale."

2.2.4 Indoor air quality

The UNI 10339 [7] standard provides indications regarding the classification and definition of the minimum requirements of the plants and values of the reference quantities during their operation.

The UNI 10339 [7] standard is applied to aeraulic systems designed for the wellbeing of people, installed in closed buildings.

The aeraulic system must allow reaching and maintaining: the conditions of quality and air movement and the thermal and hygrometric air conditions specific to the assigned functions (filtration, heating, cooling, humidification, dehumidification) in accordance with the requirements.

The plant must ensure:

- an intake of external air equal to or greater than the minimum values, for each type of intended use, referred to the number of people present, or to the surface in the plan, or to the volume of the environment (as from Table II-9) [7].
- an air movement (in the occupied conventional volume) with speeds included within the limits prescribed as in the Table II-9 below [7].

Catetogie edifici	Velocità aria in m/s Riscaldamento	Velocità aria in m/s Raffrescamento
EDIFICI ADIBITI A RESIDENZA E ASSIMILABILI		
Abitazioni civili, collegi,luoghi di ricovero, case di pena, caserme, conventi, alberghi, pensioni	Da 0.05 a 0.015	Da 0.05 a 0.20
EDIFICI PER UFFICI E ASSIMILABILI		
Uffici in genere, locali riunione, centri elaborazione dati	Da 0.05 a 0.15	Da 0.05 a 0.20
OSPEDALI, CLINICHE, CASE DI CURA E ASSIMILABILI		
Degenze, corsie, camere sterili ed infettive, visita medica, soggiorni	Da 0.05 a 0.10	Da 0.05 a 0.15
Maternità,anestesia,radiazioni, prematuri,sale operatorie	Da 0.05 a 0.10	Da 0.05 a 0.15
Terapie fisiche	Da 0.10 a 0.20	Da 0.15 a 0.25
EDIFICI ADIBITI AD ATTIVITÁ RICREATIVE ASSOCIATIVE DI CULTO E ASSIMILABILI		
Cinematografi, teatri, sale congressi	Da 0.05 a 0.15	Da 0.05 a 0.20
Musei, biblioteche	Da 0.05 a 0.15	Da 0.05 a 0.20
Luoghi di culto	Da 0.10 a 0.20	Da 0.10 a 0.20
Bar, ristoranti	Da 0.10 a 0.15	Da 0.10 a 0.20
Sale da ballo	Da 0.15 a 0.25	Da 0.15 a 0.25
Cucine ristoranti	Da 0.15 a 0.30	Da 0.20 a 0.40
ATTIVITÁ COMMERCIALI E ASSIMILABILI		
Grandi magazzini, negozi, banche	Da 0.05 a 0.15	Da 0.05 a 0.20
Quartieri fieristici	Da 0.10 a 0.20	Da 0.10 a 0.20
EDIFICI ADIBITI AD ATTIVITÁ SPORTIVE		
Piscine, saune e assimilabili	≤ 0.10	≤ 0.10
Palestre e assimilabili	Da 0.15 a 0.25	Da 0.15 a 0.25
EDIFICI ADIBITI AD ATTIVITÁ SCOLATISCHE		
Scuole materne e elementari	≤ 0.10	≤ 0.10
Aule di istituti medie superiori	Da 0.05 a 0.15	Da 0.05 a 0.20
Altri locali	Da 0.05 a 0.15	Da 0.05 a 0.20

Table II-9 : Air velocity comfort range

Categorie di edifici	**Indice di affollamento per m^2**	**Portata di aria esterna (10*e-3/s per persona)**
Luoghi di culto	0.8	6
BAR, RISTORANTI, SALE DA BALLO		
Bar	0.8	11
Pasticcerie	0.8	6
Sale pranzo ristoranti e self service	0.6	10
Sale da ballo	1	16.5
Cucine	-	16.5
ATTIVITÁ COMMERCIALI E ASSIMILABILI		
Grandi magazzini p.t	0.25	9
Grandi magazzini p.sup	0.25	6.5
Barbieri, saloni bellezza	0.2	14
Abbigliamento, calzature mobili, ottici, fioristi, fotografi	0.1	11.5
Alimentati, lavasecco, farmacie	0.1	9
Zone pubblico banche, quartieri fieristici	0.2	10
PISCINE,SAUNE E ASSIMILABILI		
Piscine (sala vasca)	0.3	2.5
Spogliatoi/Servizi	-	-
Saune	0.5	2.5
PALESTRE E ASSIMILABILI		
Palazzetti sportivi		6.5
Bowling	0.6	10
Palestre:		
Campi da gioco	0.2	16.5
Zone spettatori	1.5	6.5

Table II-10 : Fresh air flow rate

III. SYSTEMS ANALYSIS

The aim of this chapter is to find, after a rough analysis, different possible combinations of systems that could be able to satisfy all the requirements given by the DGR 967/2015 [1] of the Emilia Romagna region standard.

Looking at it, the code makes a division among the systems that produce electricity and the systems that produce thermal energy, giving, for each branch, specific regulation in terms of percentage of renewable energy that they have to use. According to this division, in this chapter will be analyzed separately the possible electricity production systems and the thermal energy production systems and, then, possible combinations of them, able to satisfy all the requirements.

The most important concept is to stay below certain limit of carbon dioxide emissions and to promote the use of renewable primary energy sources. To make a correct combination of generation and emission subsystems, having regard to limitations of the standard, the Table III-1 present in the "allegato 3" of the DGR 967/2015 [1] must be considered. This table shows the portion of renewable energy that can be considered for the calculation for each energy vector.

Energy vector	$f_{p,nren}$	$f_{p,ren}$	$f_{p,tot}$
Natural gas	1,05	0	1,05
GPL	1,05	0	1,05
Diesel oil and fuel oil	1,07	0	1,07
Coal	1,10	0	1,10
Solid biomass	0,2	0,8	1,00
Liquid or gaseous biomass	0,4	0,6	1,00
Electric energy from the net	1,95	0,47	2,42
District heating	1,5	0	1,5
Solid urban waste	0,2	0,2	0,4
District cooling	0,5	0	0,5
Electric energy from photovoltaic panel	0	1,00	1,00
Thermal energy from solar panel	0	1,00	1,00
Thermal energy from outside environment-free cooling	0	1,00	1,00
Thermal energy from outside environment – heat pump	0	1,00	1,00

Table III-1 : Energy vectors renewable percentage

Below different possible machines are proposed and then combined in four different plant solutions that will be analyzed in detail.

3.1 Electricity production

As already saw in the introduction of this chapter, the DGR 967 introduce limitations for what concern the electricity production and utilization of the building. In the code are given the following specifications:

"E' fatto obbligo in sede progettuale di prevedere l'utilizzo delle fonti rinnovabili a copertura di quota parte dei consumi di energia elettrica dell'edificio.
A tale fine è obbligatoria l'installazione sopra o all'interno del fabbricato o nelle relative pertinenze di impianti per la produzione di energia elettrica alimentati da fonti rinnovabili, asserviti agli utilizzi elettrici dell'edificio, con caratteristiche tali da garantire il contemporaneo rispetto delle condizioni seguenti:
a) potenza elettrica P installata non inferiore a 1 kW per unità abitativa e 0,5 kW per ogni 100 m2 di superficie utile energetica di edifici ad uso non residenziale;
b) potenza elettrica P installata non inferiore a P = Sq / 50, dove Sq è la superficie coperta del fabbricato misurata in m2.
I limiti di cui alle precedenti lett. a) e lett. b) sono incrementati del 10% per gli edifici pubblici."

According to this part of the code, our building must be equipped with a system capable to produce electric energy using renewable sources. The two main systems capable to do it (or at least respect the limitations in terms of percentage of renewable energy used) are analyzed below:

- photovoltaic panel: are the most direct way to convert solar radiation into electricity. This technology generates electrical power from semiconductors when they are illuminated by photons. The electricity is proportional to the light received by the semiconductors, therefore is important, before the installation, to make a preliminary study to understand if this technology can be used in the specific condition in which the building works. With the use of photovoltaic panels, the production of energy can be totally considered made from renewable sources, because does not require the use of fuel to produce electricity.

The photovoltaic effect can be produced in solid, liquid and gas materials, but the solid materials (in which can be found the semiconductors) have the highest efficiency.

There are three different cells type: mono-crystalline, multi-crystalline or amorphous. At the moment, the amorphous cells have the half of the efficiency of the crystalline cells but also the half cost. The photovoltaic panels can be a good solution for the production of the electricity needed from the building but only if enough space is available for the installation that, at the moment, is the real problem for this system. This system can be also used, coupled with other generation systems, to cover the part of energy not realized from the main generation system. In this thesis, monocrystalline photovoltaic panel will be used, with 255 W peak power [15]

- Cogeneration systems: are defined as system able to produce simultaneously electric and thermal energy near the utilization point, with high energy efficiency, using fuel as energy vector [13]. With this type of system, it will be possible to cover the electric energy needs of the building but also guarantee part of the thermal energy needs (or totally). However, these systems are not able to remove totally the emissions as they used combustive deriving from primary fossil sources, such as any power plant, producing emissions of nitrogen dioxide, carbon monoxide and particulate matter.

  Actually, is possible to have different types of cogeneration systems depending on the technology used. In the Table III-2 are showed different types of systems with the respective properties.

  The gas turbine and the internal combustion engine are the most utilized in the cogeneration systems. The gas turbine CHPs are better where there is a continuous request of electricity, and where there is the necessity to have thermal energy at high pressure.

  The internal combustion motor CHPs are instead suitable in case of considerable demand of electric energy, and vapor at low pressure with temperature till 110°C, and most important thing, when the request is discontinuous.

	units	Gas turbine	Vapor turbine	Combined cycle	CI motor	Fuel cells
Power	MWe	0,2-100	0,5-100	4-100	0,015-30	0,01-0,25
Heat/electricity ratio		1,25-2	2-10	0,5-1,7	0,4-1,7	1,1
Electric efficiency	%	15-35	10-40	30-40	25-45	35-40
Thermal efficiency	%	40-59	40-60	40-50	40-60	20-50
Total efficiency	%	60-85	60-85	70-90	70-85	55-90
Life	Year	15-20	20-35	15-25	10-20	>5
Minimum load	%	75	20	75	50	/
Installation cost	€/kWe	600-800	700-900	600-800	700-1400	>2500
Life cost	€/MWh	2-7	3	2-6	6-12	2-12
NOz	Kg/MWh	0,2-2	0,9	0,2-2	1-14	<0,01

Table III-2: Cogeneration plant types

However, these systems do not completely abolish emissions because they use fossil fuels deriving from primary fossil sources, like any power plant, producing emissions of nitrogen dioxide, carbon monoxide and particulate matter. The emissions can be reduced by 40% using biofuel.

To choose which type of system can be used for our purpose must be took into account the Table III-1 that concern the quantity of renewable energy for each type o fuel, because the choice of the system will be influenced by the energy needs of the supermarket.

Another important analysis for each system must be calculate if is necessary to take electric energy from the net if the request is higher than the energy produced. Then the percentage of electric energy produced directly in situ has to be calculated (it can be considered renewable or not depending on the fuel used for the production or totally renewable in case of photovoltaic panels) together with the percentage took from the net, that has a portion of renewable equal to 0.2% [1].

In conclusion, for the selected electricity production system, if the photovoltaic system will be excluded, should be taken into account the percentage of renewable energy, that depends on the fuel used, to understand if the system used is able to respect the limits imposed by the code.

3.2 Thermal energy

This part of the chapter is related to the thermal energy production. The part of the code that talk about this argument is the following:

"È fatto obbligo in sede progettuale di prevedere l'utilizzo di fonti rinnovabili a copertura di quota parte dei consumi di energia termica dell'edificio.
A tal fine, l'impianto termico e/o l'impianto tecnologico idrico-sanitario deve essere progettato e realizzato in modo da garantire il contemporaneo rispetto della copertura, tramite il ricorso ad energia prodotta da impianti alimentati da fonti rinnovabili, del 50% dei consumi previsti per l'acqua calda sanitaria e delle seguenti percentuali dei fabbisogni di energia primaria per la produzione di energia termica: incrementati del 10% per gli edifici pubblici."

This part of DGR 967/2015 [1] implies that the building has to be equipped with plants able to produce and provide thermal energy derived from renewable sources for at least the 50% of the total sources used (in case of public buildings). The choice of the thermal energy production subsystem is strictly related to the emission subsystem that will be used, because each emission subsystem has a specific temperature and quantity of water needed to maintain the ambient inside the comfort range, in terms of temperature and humidity.
According to what explained above, a subdivision will be made, in order to differentiate the generation and emission subsystem.

3.2.1 Emission subsystems

Among the possible emission subsystems, the first thing that must be choose is if it will be used an all-air system, so just an air handling unit, or a mixed system, that is composed by an air handling unit and a water system (fan-coil or radiant floor) that cover respectively the latent and the sensible loads. In a supermarket, where the clear internal height is much higher than the height of a normal residential building, the use of a mixed system could be a problem because are less flexible than an all air system. According to what has been said, in this thesis are analyzed systems in which the emission subsystem is an all air systems, so will be used an air handling unit.

The air handling unit is an encased assembly consisting of one or multiple fan, and other equipment like coils, to perform one or more of the functions of circulating, cleaning, heating, cooling, humidifying, dehumidifying and mixing of air. Based on the functions that the air handling unit performs, can be said that there are two different system: all-air system and mixed system. In the first one, the system that will be used, the air handling unit perform the control over both the latent and sensible loads and, consequently, the humidity and the temperature.

The operating principle of the AHU is to take air from outside and after several operations send it into the internal environment. To heat, cool, humidify and dehumidify the air, the AHU needs hot and cold water to let coils work, but also electricity to let the air flow thanks to fans.

Using an all-air system, the advantages are:

- usage of just one system (so less ducts, but bigger than the case of mixed system)
- all the production parts of the system can be positioned outside the environment (very high flexibility in terms of loads that is able to cover).

Considering the utilization of renewable sources, the air handling unit, can be equipped with a heat exchanger. It is a device used to transfer heat between two or more fluids separated by a solid wall, to prevent mixing, or in direct contact. In the air handling unit, the fluids that exchange heat are the exhaust air, that exit from the building, and the fresh air, that is took from outside. With this system, the heat that would be lost from the exhaust air is transferred to the fresh air, so less energy will be used in the next steps.

Another way to reduce the energy needs of the plants is using a Desiccant wheel inside the AHU. If a desiccant wheel is mounted In the AHU the system can be called DEC AHU [23]. This System is composed by a desiccant wheel, at least one evaporative cooler, and a heat exchanger. The desiccant wheel intermittently receives and dries a first air stream from the internal environment to produce a second air stream. The evaporative cooler receives and cool the second air stream to produce an air stream at a temperature below the dew. The heat exchanger uses this air stream to absorb heat from the ambient air to produce a fourth air flow before the fourth air stream is forced into the building. Condensate is removed from the ambient on the dry side surface of the heat exchanger. The systems that use the desiccant evaporative cooling are called DEC air handling unit.

Later will be analyzed two different types of AHU, one uses a desiccant evaporative cooling while the other doesn't. These two different types of AHU will be combined with different generation subsystems that will be studied in the chapter 3.2.2.

3.2.2 Generation subsystems

The generation system choice is strictly related to the emission subsystem that will be used in the building because, for example, some generation machines are more efficient coupled with emission systems that work with specific temperature interval. The possible generation solution in the building under analysis are:

- Cogeneration: Already described in the chapter 3.1.

- Heat pump/chiller: are devices that transfers thermal energy from a source to another. Although they use a small amount of electricity to run, heat pumps are considered highly efficient and clean because they don't depend on the burning of fuel to create the heat. They perform well in moderate climates and can provide heating during the winter, even at temperatures of -20 degrees Celsius. There are two main kinds of heat pump depending on the type of medium they extract heat from, namely air or ground/water. The big advantages in the use of a heat pump is the high efficiency, mostly if they work at low temperature, so the use of electricity to let they work is really low respect to the energy production. The parameter that describe the heat pump performance is the COP (coefficient of performance), and generally can be found in the datasheet [14].

- Solar collector: are designed to capture the largest amount of solar energy and to translate it into heat with the greatest possible efficiency [22]. There are different types of collectors, which have the same principle function but different efficiency and cost. The big disadvantage of the solar collectors is the low amount of heat produced during the winter season, when the solar radiation is low, and the heat energy requested is higher. The solution to this problem is use solar collectors coupled with an auxiliary generation subsystem that can be for example a heat pump. A thing to consider is that the energy produced by the solar collector can be taken as produced totally by renewable sources because don't use fuel to work. Solar collector can works very well coupled with DEC AHU because help the generation subsystem to produce hot water needed by the heating coil. In this thesis flat plate solar collector will be used [16].

- District heating and district cooling: District heating or cooling is a system for distributing energy generated in a centralized location through a system of insulated pipes for residential and commercial heating and cooling requirements such as space heating and water heating. The heat is often obtained from a cogeneration plant burning fossil fuels or biomass, but heat-only boiler stations, geothermal heating, heat pumps and central solar heating are also used. District heating plants can provide higher efficiencies and better pollution control than localized production systems. These systems are still not so diffused in Italy and near the site under examination is not present a district heating plant so for this study this technology won't be considered [21].

As said at the beginning of this chapter the choice of the generation subsystem is strongly affected by the emission subsystem chosen, but also to the environmental installation presents near the building site. In the next chapter, will be analyzed the possible "suitable" solutions for the building under examination.

3.3 Proposed systems

Analyzing what has been said about the possible solutions, and considering the new Emilia Romagna code [1], the generation-emission systems that will be considered in this thesis will be the followings:

- Solution 1:
  - generation system: electric chiller/heat pumps, photovoltaic
  - emission system: all air system AHU

This first configuration tries to maintain inside the "law limit" the amount of renewable primary energy using a field of photovoltaic panel for the electricity production and use a heat pump for the thermal energy needs. With this system is necessary to look at the space needed from the photovoltaic panels, because if it is not enough the building has to request energy from the electric energy provider and in this case count as non-renewable primary energy.

- Solution 2:
    - generation system: Cogeneration system, chiller/heat pump system
    - emission system: all air system AHU

The working principle of this second solution is the same of the first one but in this case the generation subsystem is composed by a CHP that covers part of the electric and thermal building energy needs. An important aspect, when a CHP is used, is to understand vector is possible to use because this technology is driven by an internal combustion engine and not all the fuels that it can use are renewable or contains part of renewable energy.

- Solution 3:
    - generation system: Cogeneration system and electric heat pump /chiller
    - emission system: all air DEC AHU

The cogeneration system is able to cover all, or a portion (depending on how it was dimensioned) of the electricity and heating building energy needs but is not able to cover the cooling energy needs, this is why must be coupled with a heat/chiller pump that makes cooling water needed. What can be expected from the simulation is that the DEC AHU has an high efficiency that reduce the energy need respect to a common AHU [24]. A thing to consider is that the cogeneration system could need to be coupled with photovoltaic panels or an auxiliary generation system because depending on the working cogeneration principle there is a specific ratio between the electricity and the heat produced, so is not necessarily true that this system is able to cover both the demands without auxiliary systems.

- Solution 4:
    - generation system: electric chiller/heat pumps, photovoltaic, solar collectors
    - emission system: all air DEC AHU

In this last case, a DEC AHU is coupled with a solar collector system that will help to reach the minimum renewable source energy usage requested by the law. A DEC will use more heated water than a normal AHU because it is able to heat up the water deriving from the ambient (till 60 degree) in order to let the desiccant wheel dehumidify the fresh air stream. This system will be also coupled with photovoltaic panel to cover a percentage of electric energy request with renewable energy.

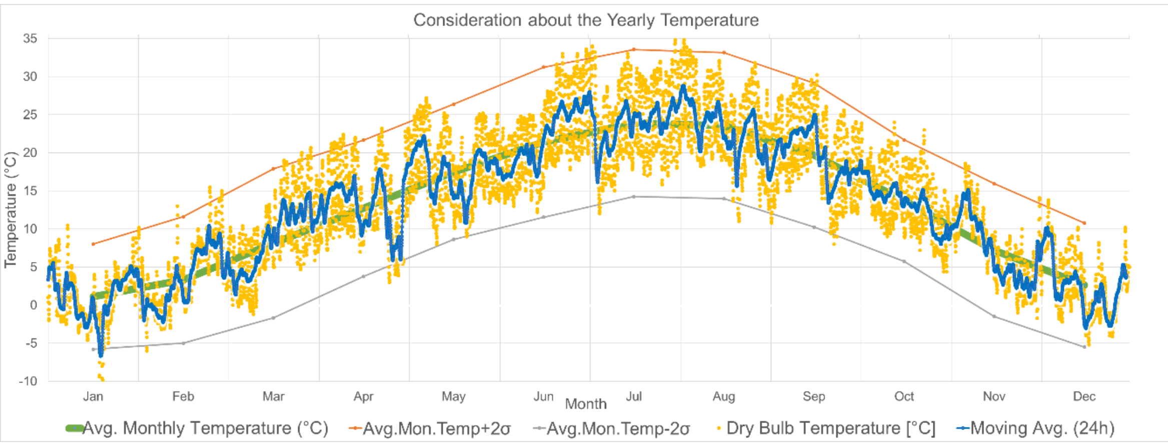
IV. WEATHER ANALYSIS

4.1 Annual temperature considerations

To analyze the climate of Emilia Romagna, combined with the fact that the location of the building is not unique, Bologna has been selected because of its position in the region in order to have a climate that can satisfy almost every condition that it's possible to find in this part of Italy. Indeed, it is in the middle between the cities near the coast and the ones placed in the Pianura Padana. Due to this Bologna has average values in terms of temperature, humidity and rainy days during the whole year.

Starting from the climate conditions of this city a graph has been plotted superimposing three graphs about dry bulb temperature (Tdb) considering:

- Line or scatter of all the *Tdb* values of the year
- The monthly average and the (montly) standard deviation of the *Tdb*
- The (monthly) upper/lower limit of the *Tdb*, calculated as the monthly average plus/minus two times the (monthly) standard deviation
- The mobile average of the the *Tdb*

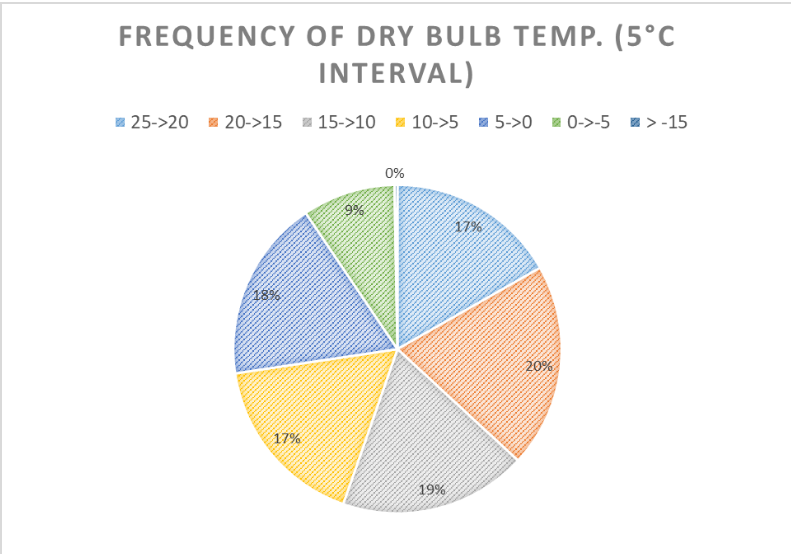


Graph IV-1 : Bologna's temperature

Analyzing the temperature, it's possible to notice that the scattering (distribution of a quantity around a mean value) of the Tdb values is quite high but the deviation interval accepted (+/- 2σ) includes almost all the scatter values all over the year.

The moving average curve isn't smooth, but this might be traduced as a possibility to take advantage of the different hourly temperatures to create heating/cooling in intermediate seasons.

The Graph IV-2 shows the distribution of the whole year temperatures divided for intervals of 5°C. It's possible to notice that the percentages are almost constant, so Bologna has an equal distribution of temperature both in winter and summer. In this type of climate temperatures goes from -5°/-10°C to 35°C so it will be necessary to have a conditioning plant but also a heating plant. This will depend also on the internal gains and the U-value of the elements but, considering the maximum and minimum temperature, they are far from the comfort condition in summer and winter (19°C/26°C) so it's reasonable to think that a cooling/heating plant will be necessary.



Graph IV-2 : Frequency of dry bulb

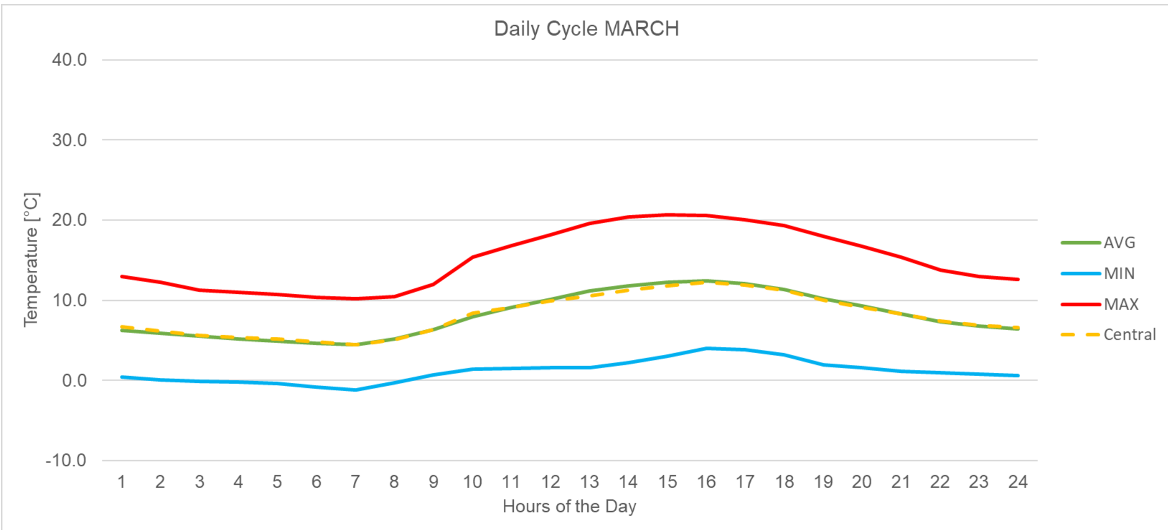
The last graph about temperature is a carpet graph that shows the temperatures all year long to have a simple graphical representation of what happens during the year. It's possible to see that precise seasons can be distinguished and for this reason there will be some periods during the year in which no heating or cooling could be needed but only with the air changes and using the temperature difference between day and night will be possible to cool/heat the building.

Graph IV-3 : Temperature distribution carpet graph

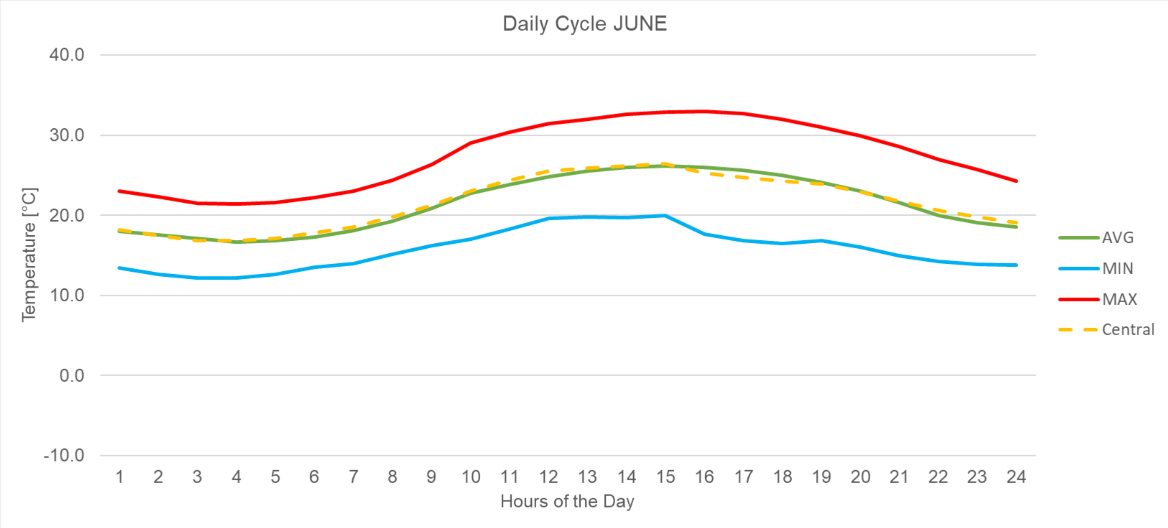
4.2 Representative daily cycle

The analysis has been carried on only considering the most significant months and, after some considerations regarding the fact that they should have been selected in function of the capability of representing almost all the different climate conditions during the whole year, solstices and equinoxes have been evaluated as the best choice. Starting from this consideration, it has been defined a reasonably representative daily cycle of Tdb, by plotting graphs for each months, where is present:

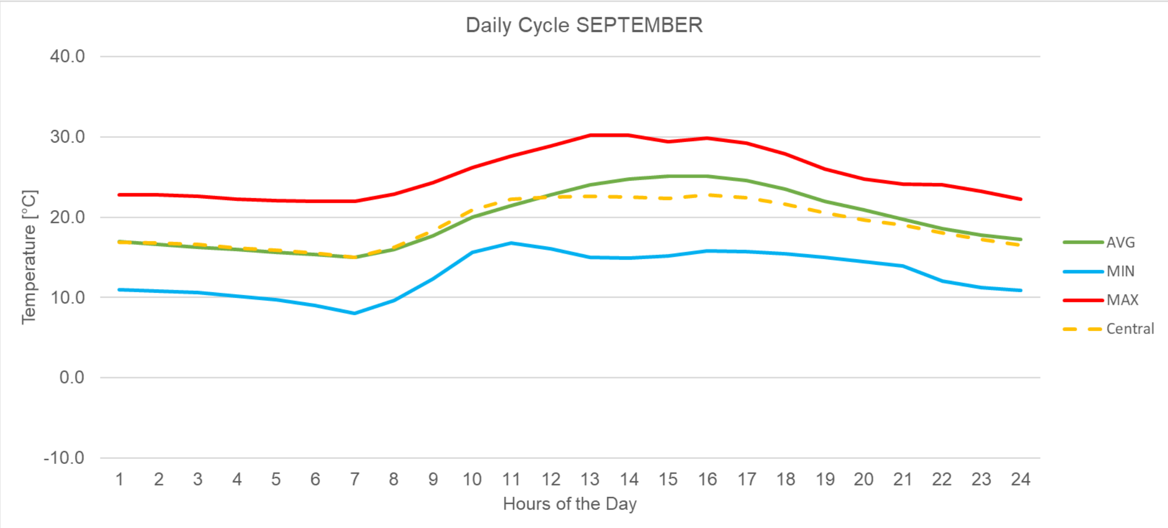
- The average hourly *Tdb* values for each month of the year
- The minimum hourly *Tdb* values for each month of the year
- The maximum hourly *Tdb* values for each month of the year
- The central hourly *Tdb* values for each month of the year



Graph IV-4 : Daily cycle March



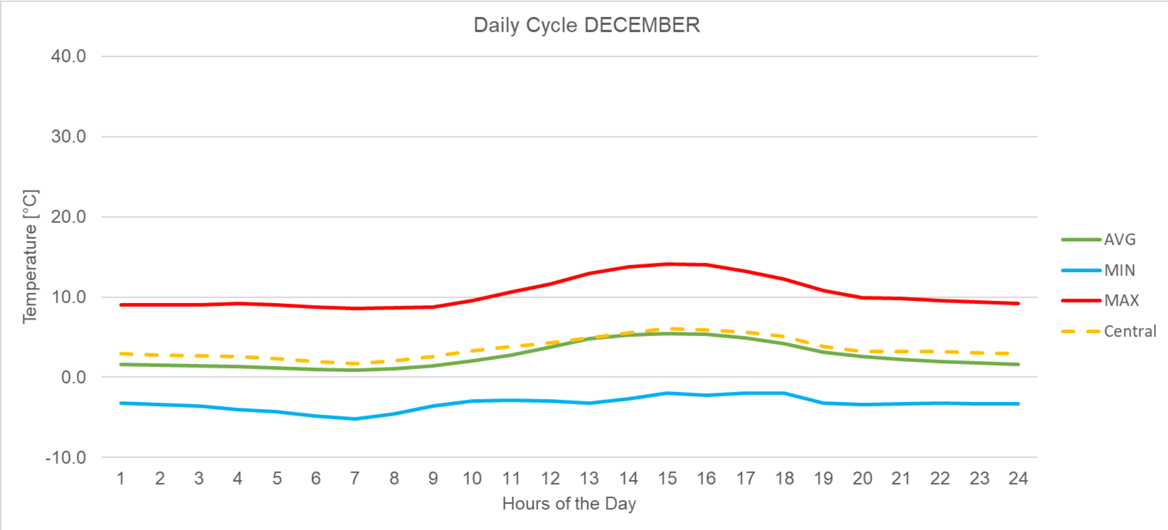
Graph IV-5 : Daily cycle June



Graph IV-6 : Daily cycle September

In this case comparing the average values of the Tdb with the central value that is the difference by hour of the max and min value, the result shows that the two curves are very similar, though, the average Tdb is a very good representation of the climate data.

The values of the Maximum/minimum hourly temperatures can be very useful in case the designer wants to take advantage of a big temperature delta all over the day to use « passive techniques » in order to reduce the DHh/DHc, for example to use night cooling in a season where at night there is a big decrease in temperature while in the morning it reaches high temperatures.



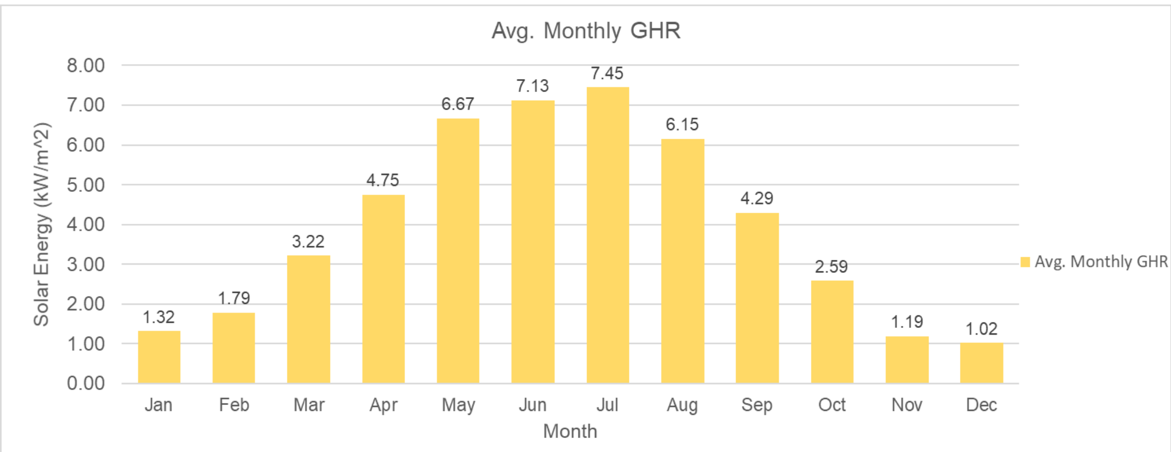
Graph IV-7 : Daily cycle December

4.3 Solar energy on horizontal surface

The third analysis has been made considering the average monthly amount of solar energy radiation received by the horizontal surface, without any kind of obstruction in (kWh/m2).

As it's possible to notice from the Graph IV-8 the radiation changes constantly with the variation of the seasons.

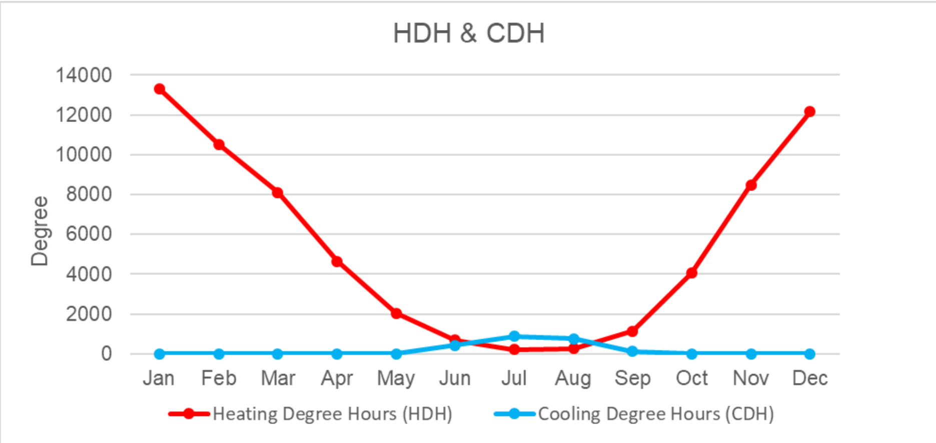
This analysis will be very important when the use of solar panel will be taken into account. More analysis of this type will be done considering also the inclination of solar panels and their orientation. But this a good starting point to understand if this type of technology brings some benefits or not.



Graph IV-8 : Average monthly GHR

4.4 Cooling and heating period

Firstly, has been set a reasonably comfort zone which is defined in the ISO 7730 standard as being "That condition of mind which expresses satisfaction with the thermal environment". This range of values is even though related to the particular city taken into account and it had been fixed starting from the most general comfort thermal conditions for which temperatures are assumed to be between 19°C and 26°C. At that point it was possible to calculate heating and cooling degree hours to understand if there's one of them that prevails on the other. The Graph IV-9 shows that predominantly it's necessary to heat the building while, as regards cooling, it's necessary only in the month of June, July and August but these considerations will be investigated after because these parameters are affected also by the physical characteristic of the building.



Graph IV-9 : Heating/Cooling degree hours

V. MODEL DEFINITION

An important thing that influences significantly the results of the simulations are the construction technologies used for the building envelope and the utilization profile of the building. The aim of this thesis is to make simulations to understand the best systems to use in the climate condition of Emilia Romagna for a supermarket accordingly to the standard given in DGR 967/2015 "Requisiti minimi di prestazione energetica degli edifici" [1] and, regarding the construction technologies, the "Impianti aeraulici ai fini di benessere" (UNI10339) [7] for the utilization profile definition.

In order to make a first load analysis with trnsys2018 [34], the building was defined in TRNBuild, that is a software which, automatically, create a trnsys Type56 [27] tool that represent, inside the trnsys environment, a multizone building that can be used for the simulations. TRNBuild [28] needs all the information, regarding the building, necessary to calculate the energy needs and thermal losses.

Following the TRNBuild schedule, the building has been modelled, inserting as first approximation an ideal plant in order to calculate the building loads to maintain the comfort conditions inside the building.

TRNBuild require an external 3D model that define the geometry of the building. Since the building hasn't defined dimensions, is supposed to be about 2000 m^2, that is a reasonable dimension for a supermarket, with a flat roof, generally used in building like that, due to the possibility to have plant positioned on it.

According to the defined dimensions the walls will have a surface of 1260 m^2 (the height is equal to 8 m and the two sides are 45 meters length), the roof and the floor has the same area of the building, so 2025 m^2. The geometry was modelled in 3D using SketchUp [35] that is able to export the building in IDF format that is the one used by TRNBuild. If the model is correctly imported in TRNBuild, is possible to have the surfaces of the wall already defined, in terms of dimension and position one respect to the other, and ready to receive a construction technology as property.

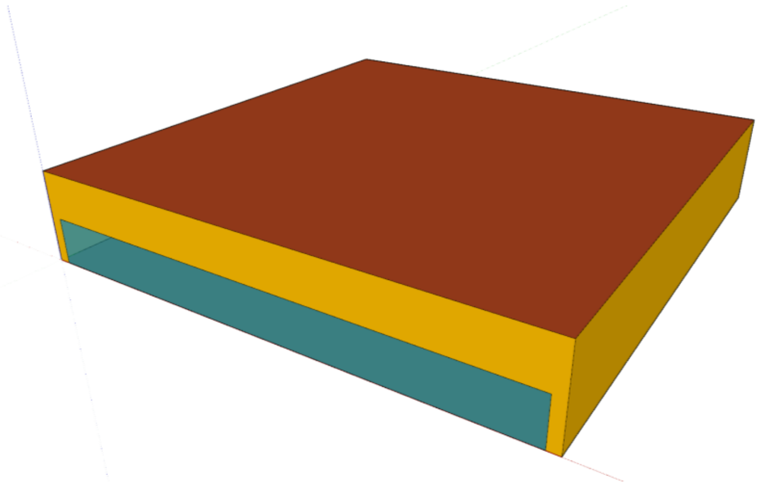


Figure V-1 : Sketchup 3-D model

After the definition of the geometry is possible to start assigning to the building all the properties that are necessary for the analysis (Figure V-1). The second step is to define the input and the output that the Type56 must receive and produce. In the table below is possible to see which the input and the output are selected.

No	Name	Unit	Description
1	TAMB	C	ambient temeprature
2	RELHUMAMB	%	relative ambient humidity
3	TSKY	C	effective sky temperature for longwave radiation exchange
4	TSGRD	C	effective ground temperature for longwave radiation exchange
5	AZEN	degrees	solar zenith angle
6	AAZM	degrees	solar azimuth angle
7	GRDREF	any	ground reflection
8	TGROUND	C	ground temperature
9	TBOUNDARY	C	boundary temperature
10	SAHDE_CLOSED	kJ/hr.m^2	threshold of total radiation on facade where is activated
11	SHADE_OPEN	kJ/hr.m^2	threshold of total radiation on facade where is deactivated
12	SUPPLY_AIR	C	temperature air from heat exchanger
13	RH_SUPPLY	%	relative humidity from heat exchanger

Table V-1 : TRN build input

As output of the analysis were selected all the results concerning the internal environment behaviour, focusing on the internal comfort conditions and the energy needs (the list input and output lists are showed in Table V-2).

No	Name	Unit	Description
1	TAIR	C	air temperature of airnode
2	QHEAT	kJ/hr	heating demand
3	QCOOL	kJ/hr	cooling demand
4	QGPEOPLE	kJ/hr	sensible energy gain from people
5	QINF	kJ/hr	sensible infiltration energy gain
6	QVENT	kJ/hr	sensibile ventilation energy gain
7	QLATD	kJ/hr	latent energy demand of airnode
8	QGLIGHT	kJ/hr	sensible energy gain from lights
9	QGEQUIP	kJ/hr	sensible energy gain from equipment
10	QSENS	kJ/hr	sensible energy demand of airnode
11	QLATG	kJ/hr	latent energy gains incl. Vent, inf, and gains
12	QGTHB	kJ/hr	sensible energy gain from thermal bridge
13	QDEHUM	kJ/hr	latent energy demand by dehumidification
14	QHUM	kJ/hr	latent energy demand by humidification
15	QTABSI	kJ/hr	total radiation absorbed and transmitted inside airnode

Table V-2 : TRNbuild output

5.1 Construction technologies definition

After the input and output definitions, the construction technologies have been modeled and then assigned to each element of the building envelope.

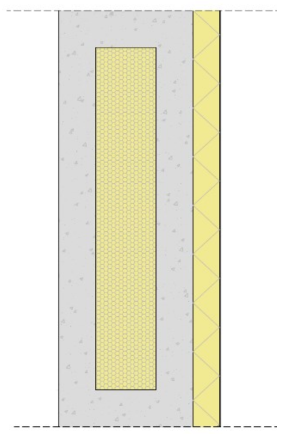
In the chapter 2 can be found the building envelope specifications, contained in the DGR 967/2015 [1]. As the building under analysis for the national code is situated in “ZONA E”, can be done a recap of the specifications as follow:

- Opaque vertical structures in contact with the external environment or with a non-conditioned space:
  U = 0,26 W/m^{2}K
- Opaque horizontal and inclined roof structures, in contact with the external environment or with a non-conditioned space:
  U = 0,22 W/m^{2}K
- Opaque horizontal pavement structures, in contact with the external environment or with a non-conditioned space:
  U = 0,26 W/m^{2}K
- Glass facade, in contact with the external environment or with a non-conditioned space:
  U = 1,4 W/m^{2}K
  Solar transmittance of the glass façade g = 0,35

Following these standards, the construction details of the simulations model are designed as described below.

5.1.1 Vertical opaque façade

The vertical opaque façade is composed by a pre-casted concrete panel lightened thanks to an insertion of insulation material. This opaque façade is fast to build up and has high performance, indeed has a very low thermal transmittance (U = 0,192 W/m²K).

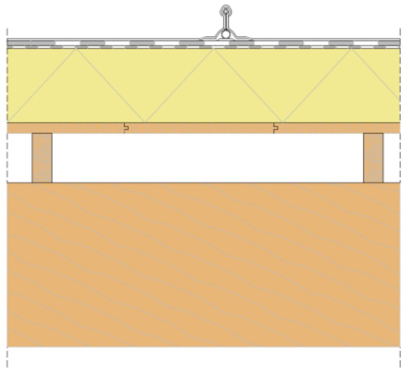


Material	Thk. (cm)	Conductivity (W/mK)
Precast concrete panel with insulation layer	25	0,07
EPS insulation layer	5	0,035
Finishing	1	
Thermal transmittance	W/m²K	0,192

Table V-3 : Vertical closure

5.1.2 Roof

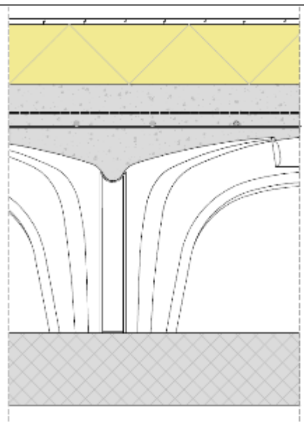
The roof is composed by a wood structure, composed by primary and secondary beams, then there is a wood deck that composed the plane on which is located the thermal and acoustic insulation layer needed because the top of the roof made by a metal sheet, preceded by a double waterproof layer. The wood structure is popular among the supermarket, because characterizes the internal environment and can be left without finishing let the plant installation free to be visible from the client. The thermal transmittance of this technology is 0,210 W/m²K



Material	Thk. (cm)	Conductivity (W/mK)
metal sheet	0,3	22
Double waterproof membrane	1,5	0,2
EPS insulation layer	15	0,035
Wood deck	3	0,125
Thermal transmittance	W/m^2K	0,210

Table V-4 : Roof closure

5.1.3 Floor

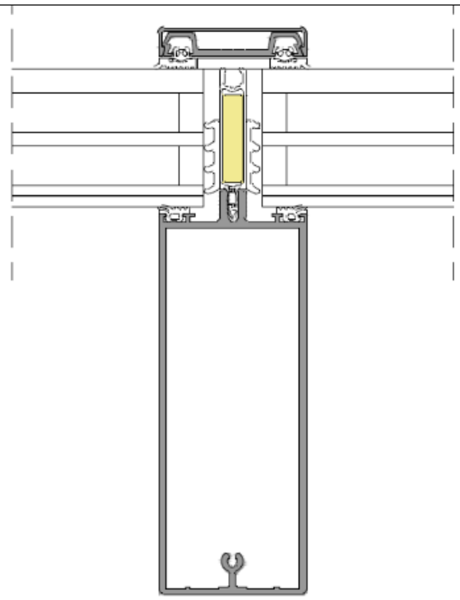


Material	Thk. (cm)	Conductivity (W/mK)
Ceramic superficial covering layer	1	1,3
EPS insulation layer	15	0,035
Sand light layer, concrete and aggregates in expanded clay	7	0,7
Bearing reinforced concrete with welded mesh layer	5	1,6
Ventilation layer with plastic elements	50	-
Thermal transmittance	W/m^2K	0,218

Table V-5 : Horizontal closure

The floor is composed by a ventilation layer, that prevents the formation of condensation product inside the internal environment, then there is a light layer of concrete that gives planarity to the system, and then the insulation layer and the finishing. In case in the building will be used a radiant floor, as thermal regulation system, it will be positioned over the insulation layer to avoid thermal dissipation through the soil. At the end the thermal transmittance of the floor is 0,218 W/m^{2}K.

5.1.4 Curtain wall



Material	%	Thermal tr.(W/mK)
FW50 system by Schuco	10	1,5
Triple glass	90	1
Thermal transmittance	W/m^{2}K	1,05

Table V-6 : Curtain wall

This curtain wall is taken as example to understand which is the possible thermal transmittance that can has a curtain wall positioned, as is customary to do, on the entrance of the supermarket. The thermal transmittance of this façade is 1,05 W/m^{2}K.

5.2 Internal and external loads

To complete the inputs, it will talk now about the minimum air changes and the internal loads in order to have all the data to make a simulation of the building.
In the Table V-7 are shown all the different types of gain and in which way they interact with the building. The estimation of the gains will be analyzed later.

Heat source	Interaction with the building
Window	Conduction through windows
Wall	Conduction through external walls
Roof	Conduction through roof
Floor	Conduction through floors over unconditioned spaces
Ground	Conduction through the ground slab
Equipment	Internal gain from equipment
People	Internal gain from people
Infiltrations	Convection through infiltrations (does not include outside air introduced by the system)
Lights	Internal gain from lights (radiation)
Solar	Solar gain through windows (radiation)
Outside air	Convection through outside air introduced by the system

Table V-7 : Heat source

As already said in the second chapter the minimum air changes per hour is regulated by the UNI 10339. This standard not only regulates how much air it's necessary to introduce in the building but also its ideal velocity in order not to have a discomfort for the final users.

In particular, for the category of building studied in this thesis, the standard suggests:

	Heating air velocity (m/s)	**Cooling air velocity (m/s)**	**Crowding index (pp/m^2)**	**Air flow (10^-3 m³/s/pp)**
Supermarket	0.05 – 0.15	0.05 – 0.2	0.25	9

Table V-8 : Minimum ventilation from standard

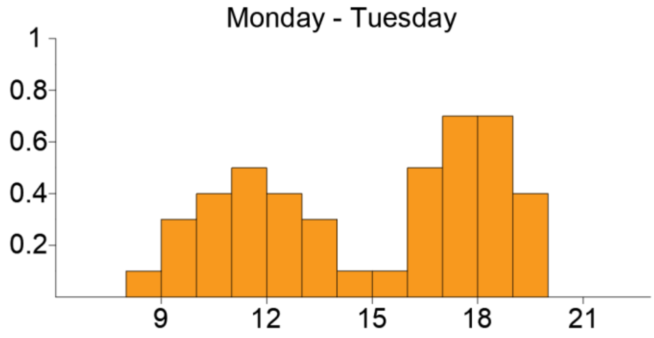
This parameter has been set in the voice "ventilation" on TRNBuild [28] as shown in the picture below:

VENTILATION TYPE MANAGER	
Volume flow rate	18252 m³/h*Plants Weekly
Supply air	Internal calculation
Temperature of supply air	External air with 0.7 of heat recovery
Humidity air flow	Outside air (Abolute humidity)

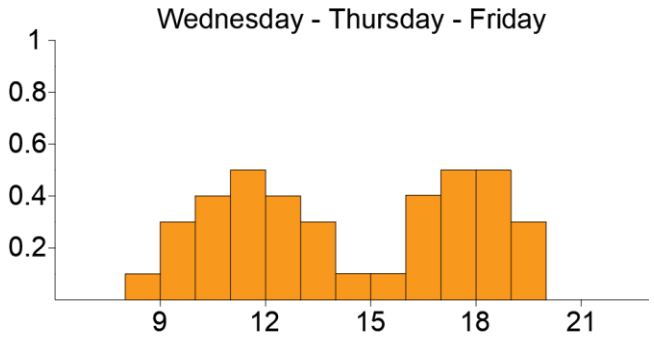
Table V-9 : Ventilation TRN build input

5.2.1 Crowd profile and people gains

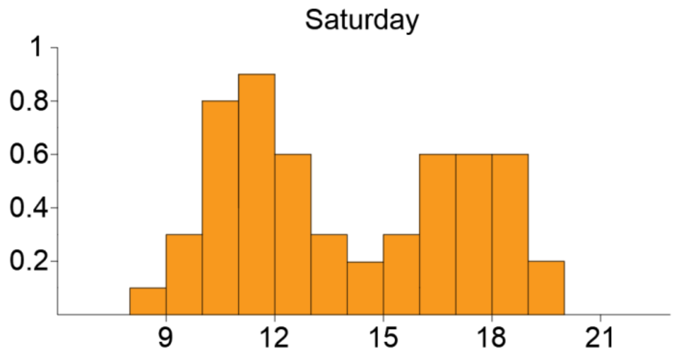
Regarding the crowding profile some supermarket in the considering zone has been studied. The following graphs show how the number of people present in the supermarket change during the single day but also during the whole week. This type of profile will be very useful to calculate the sensible and latent load produced by people in the building [8]. Moreover, using this type of schedule also the plants will be modulated following these paths in order to have always the best comfort conditions possible using less energy.



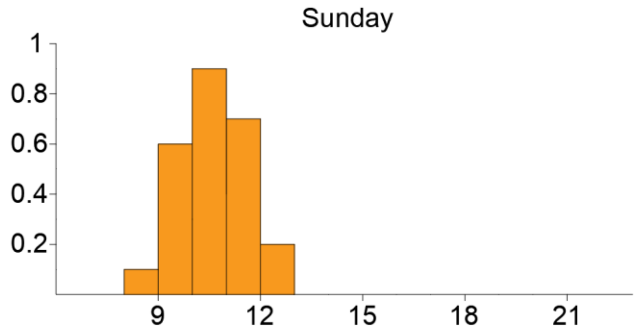
Graph V-1: Monday-Tuesday people schedule



Graph V-2 : Wednesday-Thursday-Friday people schedule



Graph V-3 : Saturday people schedule



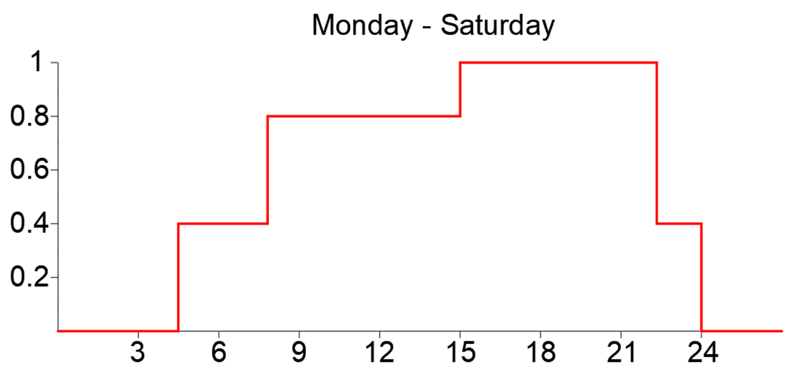
Graph V-4 : Sunday people schedule

Now that a crowding profile has been defined the next step is to understand how much heat a single person produces. This value is related to the activity that a person is doing in that moment but also to the dry bulb temperature of the building. Regarding this last argument there's something more to say. The heat releases by the human body can be divided in two contributes: the sensible heat (related to change in temperature) and latent heat (related to a phase change between liquid gas and solid). So the heat release by a human body, at the same degree of activity, changes its division between latent and sensible according to the temperature of a room. Considering a standing man in a room at 28°C it will produce 130W (50W sensible and 80W latent); if the temperature decreases until 20°C the man will produce 130W as well but 86W of sensible heat and 44W of latent [8].

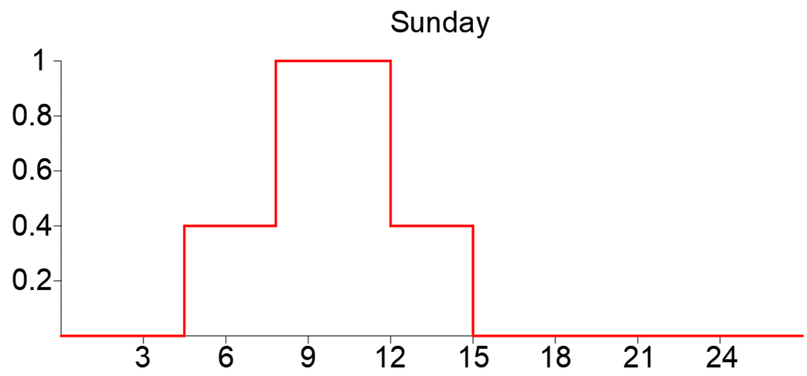
Made this hypothesis the sensible and latent heat produced by a person in a supermarket doesn't change too much according to the temperature so the value of heat produced will remain the same all year long and equal to 160W (83W sensible and 77W latent) [8].

5.2.2 Plants schedule

The same procedure done for the crowding profile has to be done for the plants. In a supermarket the HVAC system works 24/7 but at different rates of power. Considering the opening hours and the presence of people inside the building the following profile has been projected.



Graph V-5 : Monday-Saturday plants schedule



Graph V-6: Sunday plants schedule

Regarding the set temperature for heating and cooling has been selected 20°C for winter and 26°C for summer. The ideal humidity ratio has been set at 50% in both periods as shown.

HEATING TYPE MANAGER	
Set temperature	20°C
Humidification set	50%

Table V-10 : Winter set-point

COOLING TYPE MANAGER	
Set temperature	26°C
Humidification set	50%

Table V-11 : Summer set-point

5.2.3 Equipment gains

Another type of gain in a supermarket is given by freezers and refrigerators. They are always on and produce a large amount of heat (both sensible and latent). This must be taken into account in the calculation. The standard where the heat releases by these machines can be found is the ASHRAE Fundamentals handbook [8] and data sheets [18][19]. The following values are taken from tables of that standard.

Type	Quantity	Sensible heat/each	Latent heat/each	Total heat/each	Sensible total [W]	Latent total [W]	Total [W]
Freezer	40 m^3	270 W/m^3	0	270	10800	0	10800
Refrigerator	190 m^3	310 W/m^3	0	310	58900	0	58900
Monitor	20 units	55 W/unit	0	55	1100	0	1100
Total equipment heat gain [W]							**70800**

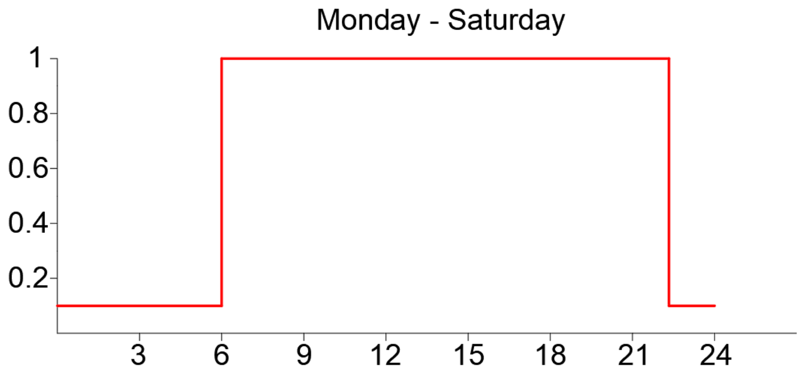
Table V-12 : Equipment gains

5.2.4 Lighting heat gains

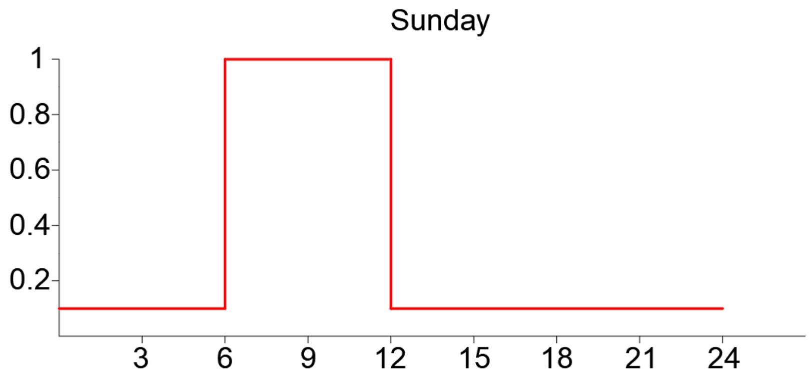
Another type of gain that it's necessary to take into account is the one creates by lighting. In a supermarket lights are on during the opening hours and partially on the other hours of the day. So first of all, it's necessary to create a lighting profile and then analyze how much watt of power are necessary to light up the building.

In this case the lighting profile is quite simple and can be described with the following graphs.

All the electrical energy used by a lamp is ultimately released as heat. The energy is emitted by means of conduction, convection or radiation. When the light is switched on the luminaire itself absorbs some of the heat emitted by the lamp. Some of this heat may then be transmitted to the building structure, depending on the manner in which the luminaire is mounted. The radiation energy emitted from a lamp will result in a heat gain to the space only after it has been absorbed by the room surfaces.



Graph V-7: Monday-Saturday equipment schedule



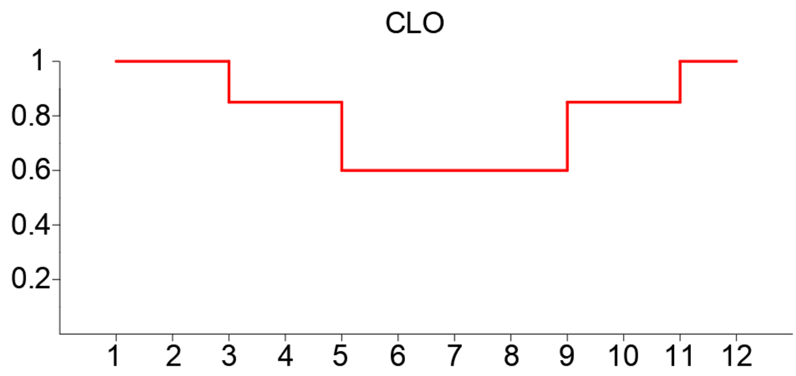
Graph V-8 : Sunday equipment schedule

Using the ASHRAE Fundamental Handbook [8] regarding the supermarkets, considering that mostly the lighting is made using LED, the gain due to lighting is equal to 2 W/m^2 [17].

5.2.5 Comfort

The last step is about the comfort of the final users of the supermarket. To face this problem 2 important values have to be taken into account: the CLO and the MET.

The CLO is the thermal insulation provided by clothing. This parameter is strictly related to the temperature comfort in a room or a building. Considering that in a supermarket the internal temperature varies between winter and summer (usually 20°C in winter and 26°C in summer) also the CLO of the people will vary as well in the different seasons. Due to that also a schedule for the CLO has been studied (all the values have to be multiplied by 1.2 as shown in the picture from TRNBuild [28]):



Graph V-9 : Comfort schedule

Regarding the MET considering the ASHRAE Handbook for a person doing shopping the value to use is 1.6. Obviously, this value is constant all over the year.

COMFORT TYPE MANAGER	
Clothing factor	1.2*Supermarket_CLO
Metabolic Rate	1.6 met
Relative air velocity	0.1 m/s

Table V-13 : Comfort type manager

The Table V-14: Maximum heat produced by internal gains below summarizes the maximum heat in Watt for the gains inside the building.

MAXIMUM HEAT PRODUCED [WATT]	
People	81000
Equipment	70800
Lights	4050

Table V-14: Maximum heat produced by internal gains

VI. ENERGY NEEDS ASSESTMENT

The aim of this chapter is to calculate the thermal loads that an ideal plant has to provide to maintain the internal comfort condition, in terms of temperature and relative humidity. This step is very useful to identify potential critical issues for the four different types of plants in the climate condition under analysis.

The model defined in the previous chapter using TRNBuild [28] has been imported in trnsys simulation studio [34] using the Type56. The type 56 represents a multizone building and in it are contained all the information defined in TRNBuild that will be used for the calculations. To the building model type 56 are connected 3 different tools:

- Weather data: all the climate information are stored in this type thanks to the EPW file provided by energy plus
- Variables: in this component are stored all the variables necessary to the simulation
- Ground: this type in trnsys is used to calculate the ground temperature condition.

From the building component in trnsys, after the simulation, is possible to carry out the results deriving from the output defined before in TRNBuild. To show the results have been used 4 plotters without external file that showed directly on trnsys the graph relative to the quantities inserted as input and one Type25a [27] that is used, in this case, to plot an external file for a post-use in excel of the simulation results. The city used to define the weather data file is Bologna that is one of the biggest cities in Emilia Romagna region [36].

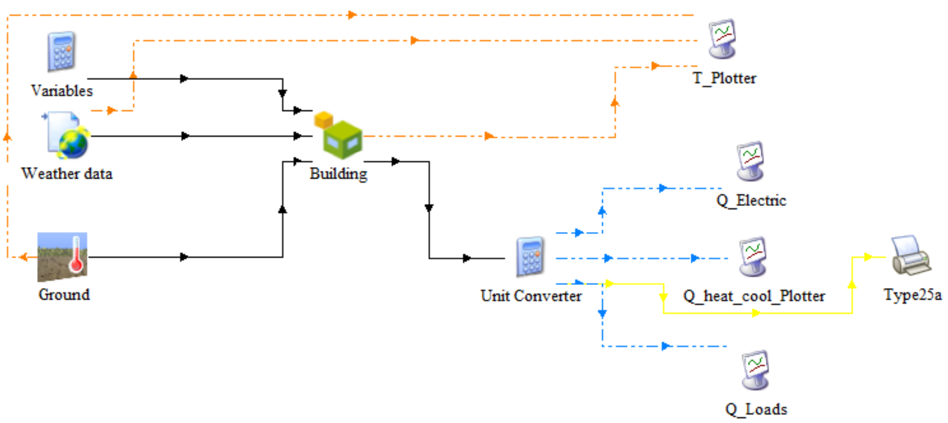


Figure VI-1 : Trnsys home page

To understand better all the needs and power that the plants require, has been decided to divide whole structure in 4 steps as shown in Figure VI-2. In this chapter the first part and an introduction to the second one will be made while the others will be analyzed later.

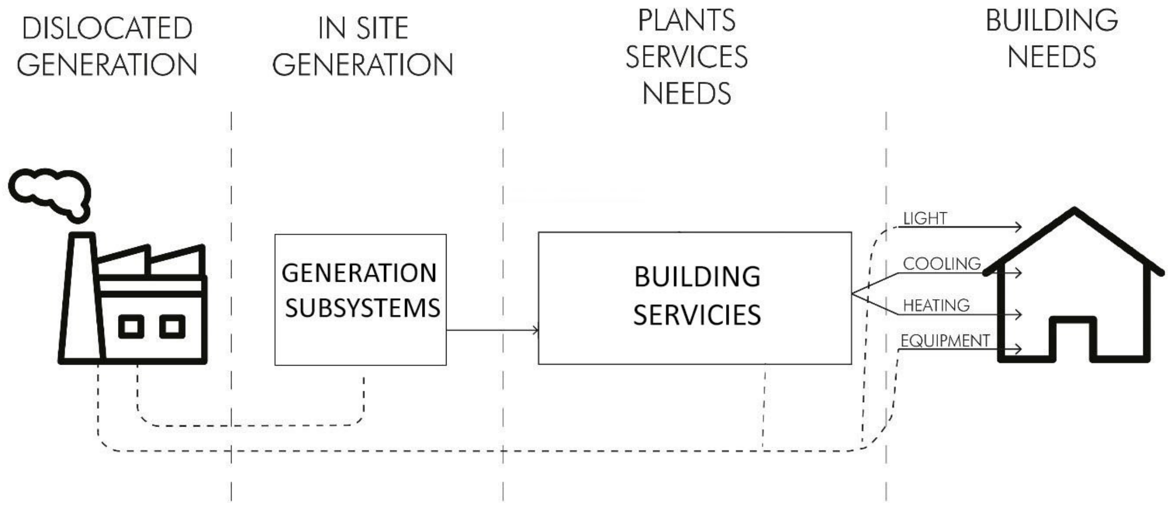


Figure VI-2: Energy consumption scheme

6.1 Building needs

Here will be described the total needs of the supermarket as sensible and latent loads, the peak power for heating cooling, humidification and dehumidification (that will be fundamental to choose the right machines for the plant) and the electrical power for lighting, refrigerators and electrical equipment like computers and monitors.

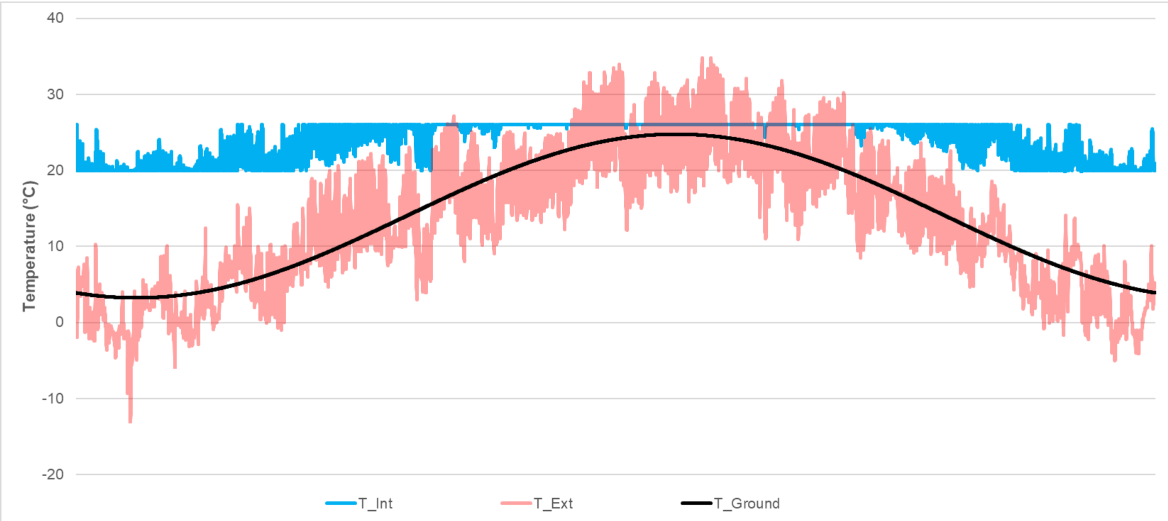
Two different types of analysis have been carried out:

- the first one considers the plants as "always on", so the temperature is taken at 20 or 26°C according to the season also during the night
- the second one takes into account the plants as "schedule mode", so they are on from few hours before the opening hours to few hours later the closing.

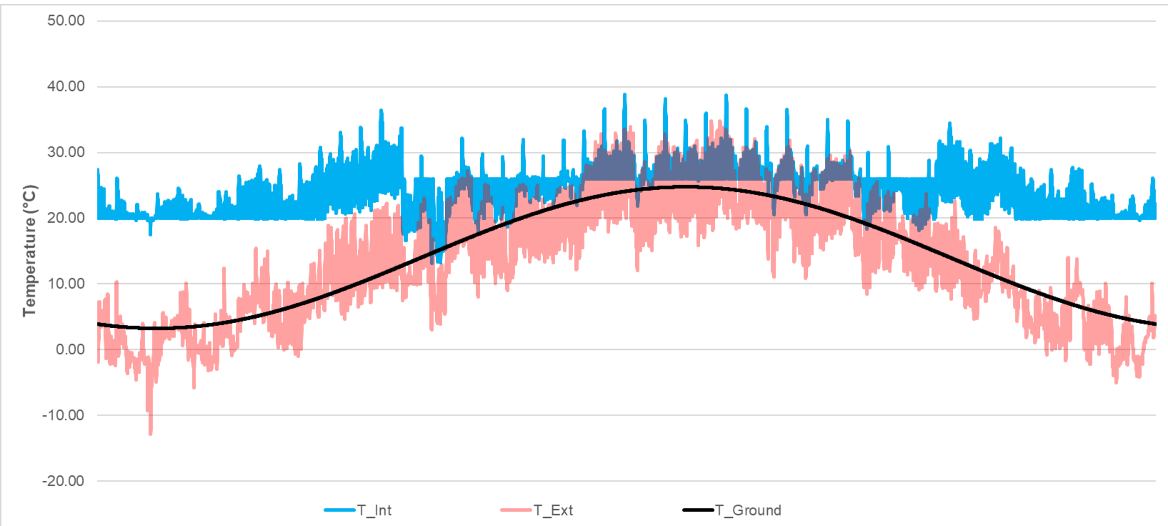
These types of analysis have been performed to understand better which one is the best schedule for the plants in terms of efficiency and consumptions both for heating and cooling.

The first graphs (Graph VI-1 and Graph VI-2) carried out from these analysis show the temperature profile of the inside air, the outside air and the ground. As it can be seen the inside air is maintained inside the comfort range previously defined in

TRNBuild (20°C in winter and 26°C in summer) for the first analysis while is quite different for the second one, in fact, temperatures increase during the night due to the high internal gains. For this step, this type of graph is not so useful because as the plant has unlimited power can easily maintain the temperature inside the comfort range, instead will be very useful in the further analysis where the plants couldn't be able to keep the temperature inside the comfort range. The profile of the outside air is the same of the one defined in the chapter related to the climate analysis. The ground temperature profile is characterized by less fluctuation respect to temperature profile because the temperature is supposed to be more stable in depth due to the indirect contact with external air, and is calculated through trnsys in order to use it as boundary condition for the ground floor.



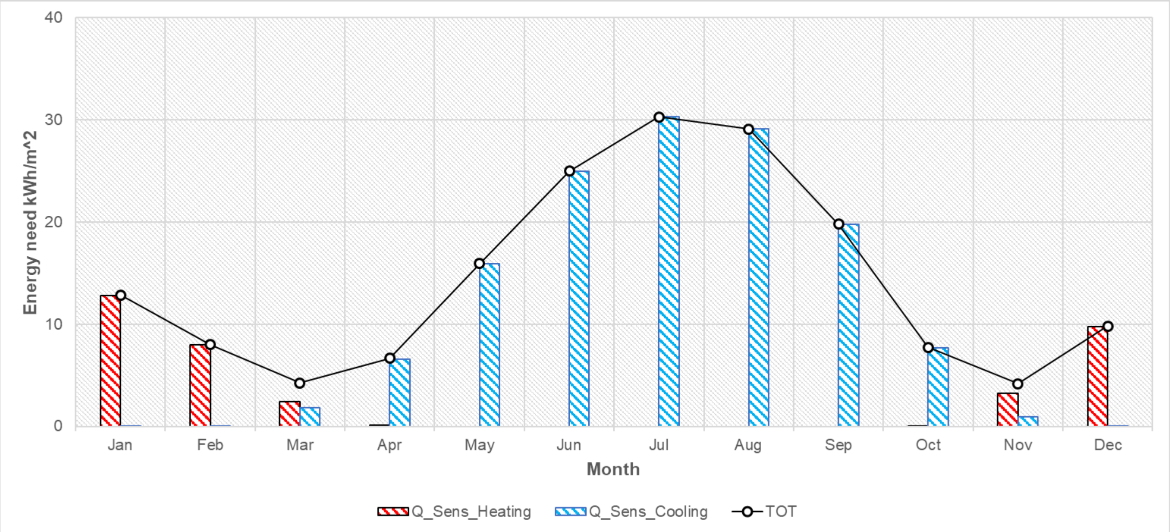
Graph VI-1 : Temperature profile "always on"



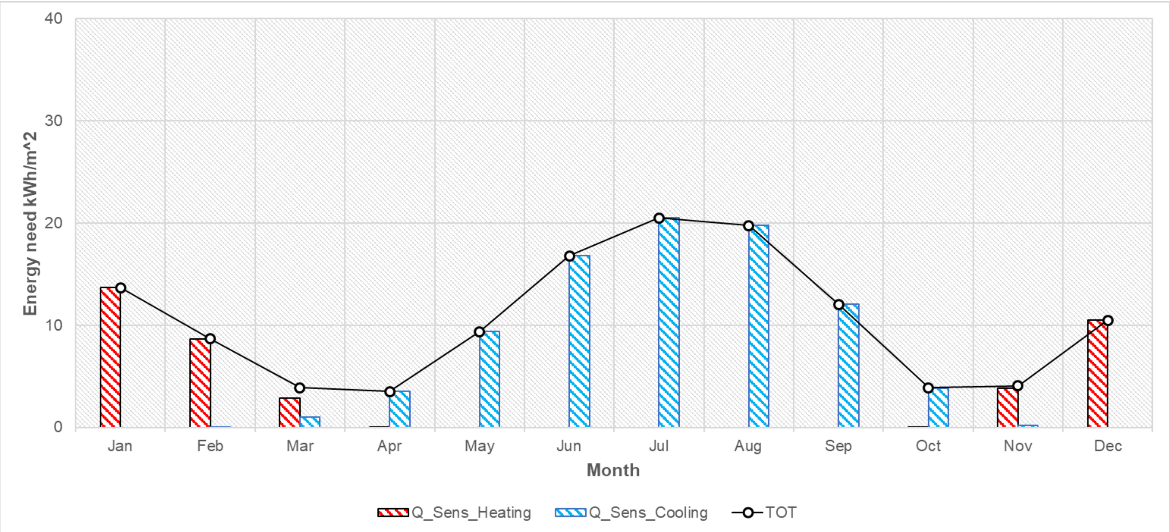
Graph VI-2: Temperature profile "schedule mode"

The Graph VI-3 and Graph VI-4, carried out from Trnsys, is related to the plant energy demand.

From the following graphs it's possible to understand better which choice is the best one helped also by the Graph VI-1 and Graph VI-2. In fact, even if the temperature profile seems to be worse, the total energy for cool down and heat up the building is lower. As visible in the graphs the cooling energy demand is higher during the year, this is due to the internal gains that a supermarket has (in particular gain deriving from people, lighting and equipment).



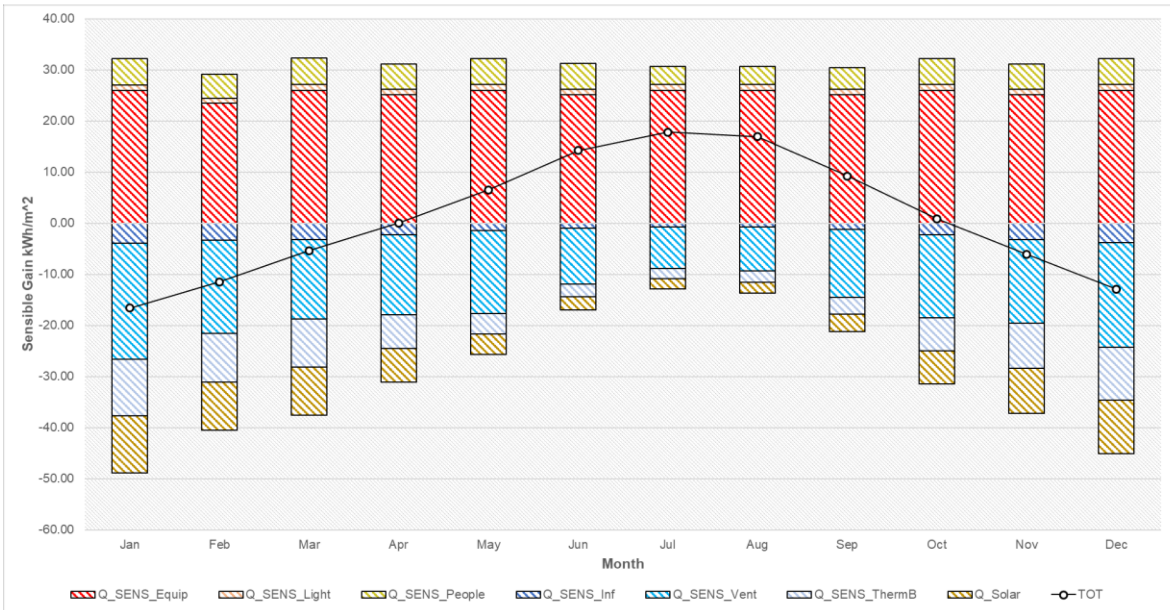
Graph VI-3 : Energy needs "always on"



Graph VI-4: Energy needs "schedule mode"

Seeing this the best solution is obviously the “schedule mode” then from now on all the graphs will be referred to this plant mode.

As said before, to make some hypothesis on which type of plants will be better for the building under analysis is important to understand which kind of loads are higher in the supermarket. According to what said, the Graph VI-5 gives all the values related to the sensible loads, dividing them into monthly gains and losses. Is visible that the sensible loads are much higher in the summer season because the loads related to the temperature difference are lower and that implies the increase of the energy needs to cool the environment. Moreover, the total cooling need is higher; this because in summer, when the losses due to infiltrations are lower and the temperature higher, it’s more difficult to dissipate the internal gains from people and equipment. For these reasons a system that can manage both heating and cooling will be installed. In the Graph VI-5 and in the Table VI-1 is visible the subdivision of the total sensible loads.

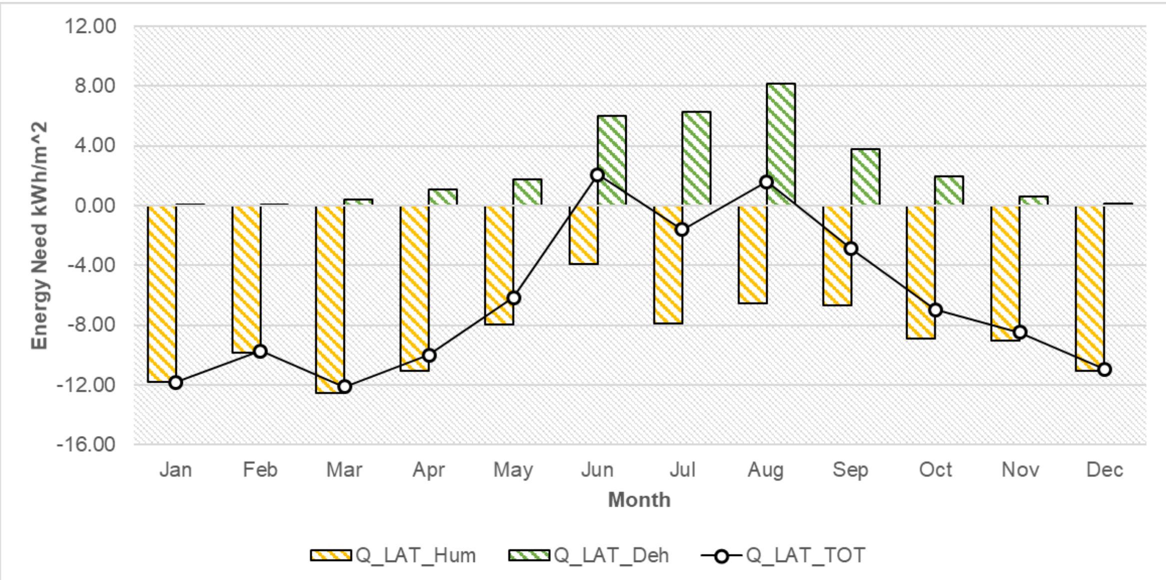


Graph VI-5 : Sensible gains

The choice of the plants is also related to the latent loads. The Graph VI-6 allows us to understand that the latent loads due to the humidification are present along all the year, instead the dehumidification loads are confined during the summer period. It can be concluded that there must be a system that during the summer period will be able to humidify and dehumidify the environment, all the systems supposed before are able to support the latent loads along all the year without any problem of limited power or limited space (due to the construction technologies), so what is expected is that the choice of the system will be more influenced by the sensible loads.

Month		Q_SENS_Equip	Q_SENS_Light	Q_SENS_People	Q_SENS_Inf	Q_SENS_Vent	Q_SENS_ThermB	Q_Solar	TOT
Jan	1	25.98	1.09	5.15	-3.97	-22.66	-11.10	-11.10	-16.61
Feb	2	23.49	0.99	4.62	-3.33	-18.20	-9.52	-9.52	-11.47
Mar	3	26.01	1.09	5.16	-3.19	-15.58	-9.42	-9.42	-5.35
Apr	4	25.17	1.06	4.91	-2.27	-15.60	-6.61	-6.61	0.04
May	5	26.01	1.09	5.12	-1.44	-16.22	-4.03	-4.03	6.50
Jun	6	25.17	1.06	5.00	-0.97	-10.90	-2.58	-2.58	14.21
Jul	7	26.01	1.09	3.56	-0.73	-8.18	-1.98	-1.98	17.80
Aug	8	26.01	1.09	3.56	-0.76	-8.57	-2.20	-2.20	16.94
Sep	9	25.17	1.06	4.18	-1.18	-13.30	-3.34	-3.34	9.24
Oct	10	26.01	1.09	5.15	-2.30	-16.27	-6.42	-6.42	0.84
Nov	11	25.17	1.06	4.94	-3.19	-16.41	-8.82	-8.82	-6.07
Dec	12	26.01	1.09	5.13	-3.78	-20.45	-10.46	-10.46	-12.92

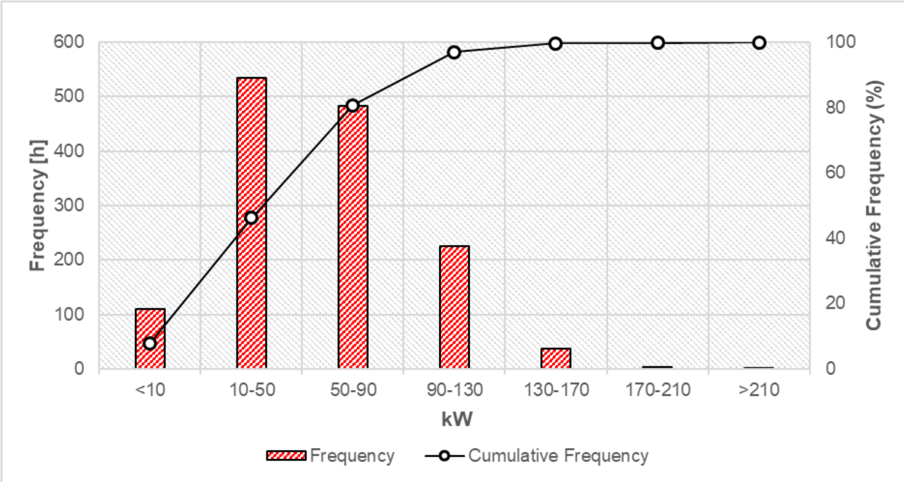
Table VI-1 : Sensible gains



Graph VI-6 : Latent gains

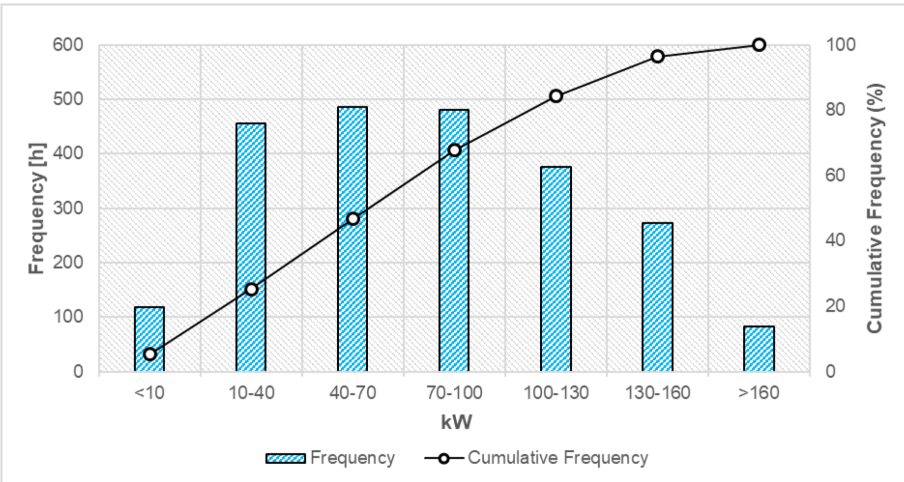
Considering the heating and cooling is useful also to understand which the load peaks are and how is the frequency distribution.

For what concern the heating, the peak power is recorded in 19th January at 10:00 and is about 229.55 kW but, studying the distribution frequency the 90% of values are under 120 kW.



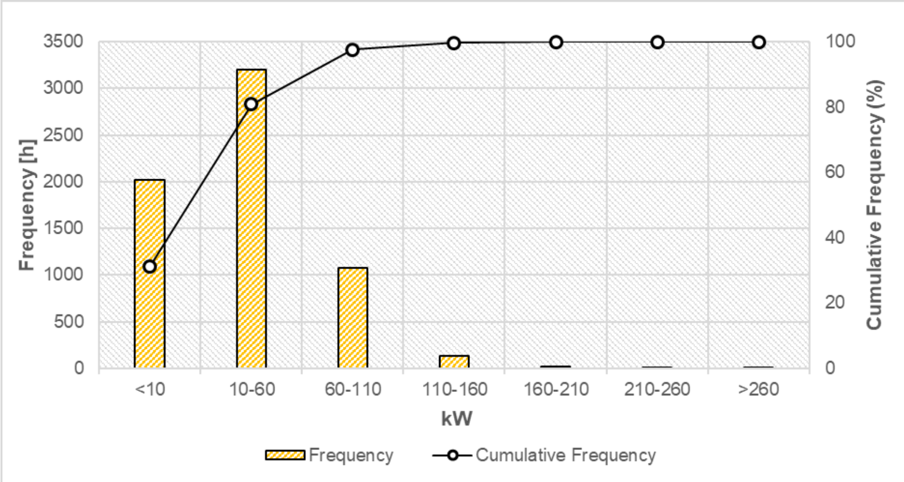
Graph VI-7 : Heating energy demand

The cooling load peak is on 23th June at 18:00 and is 196.34 kW but also in this case is possible to reach the 90% of values below 150 kW.



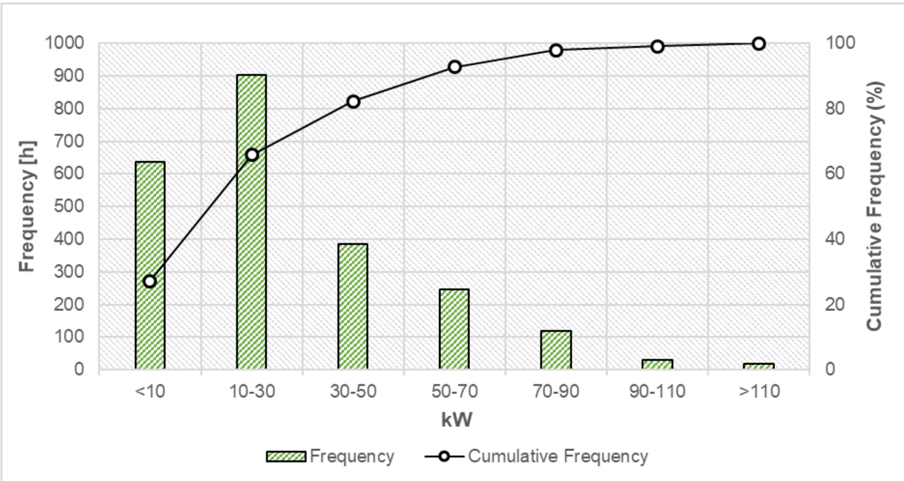
Graph VI-8 : Cooling energy demand

Considering the latent load peaks, for humidification the peak is on 27th March at 17:00 and is 293.62 kW and in this case the situation is even better because the 90% in reached around 80 kW.



Graph VI-9 : Humidification energy demand

The same speech can be done also for the dehumidification loads where the peak is 138.06 kW on 22th June at 18:00 but more than the 95% of the load is below 90kW as show in the Graph VI-10.



Graph VI-10 : dehumidification energy demand

To summarize the results obtained the Table VI-2 shows the total gains divided by type. This will be the starting point to design the plants and choose the right machines.

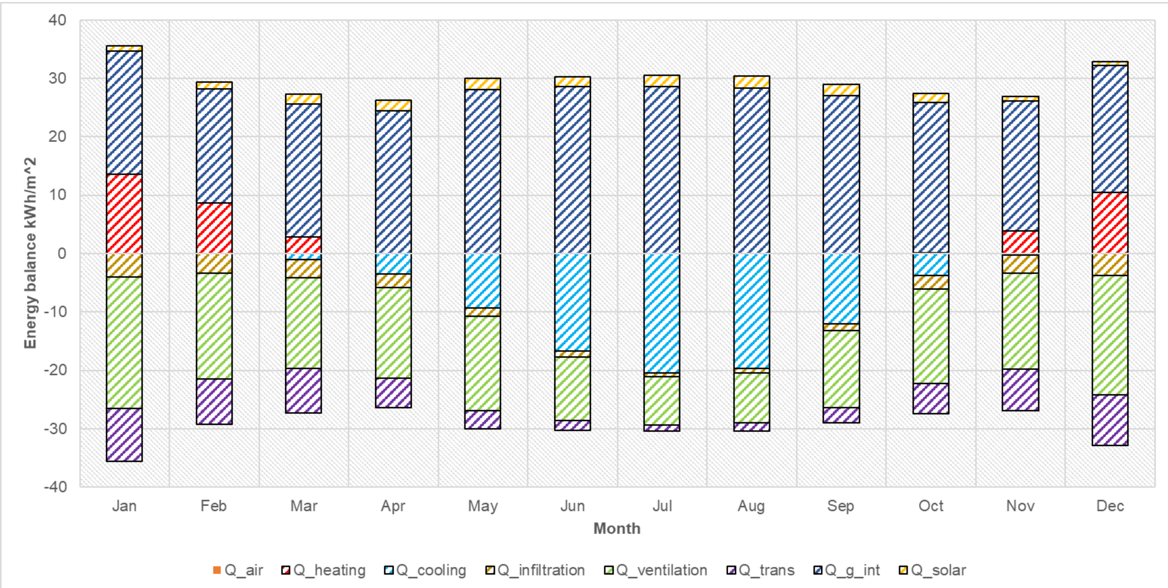
Sensible Heating (kWh/m^2)	Sensible Cooling (kWh/m^2)
39.66	87.03

Humidification (kWh/m2)	Dehumidification (kWh/m2)
107.22	30.18

Total Heating (kWh/m2)	Total Cooling (kWh/m2)
146.88	117.21

Table VI-2 : energy needs summary

Another parameter that is interesting to analyze is the balance between the heating and cooling load and the losses that the building has during the year. This balance, as shown in Graph VI-11 doesn't take into account only the sensible part but also the latent part and give a complete summary of what happens in the supermarket all year long.



Graph VI-11: Yearly energy balance

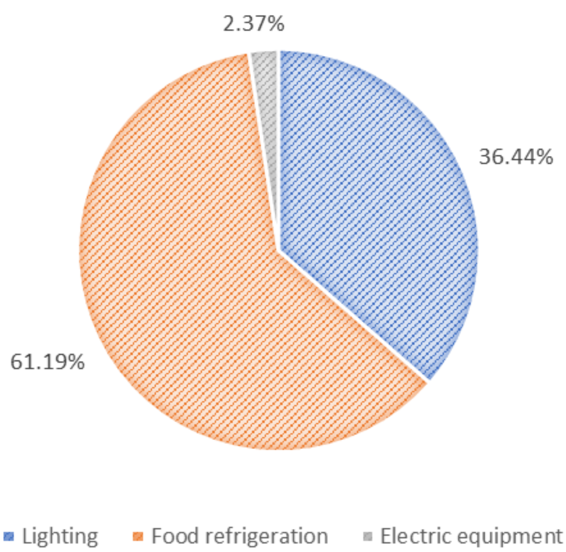
At the end of this first simulation can be observed that the energy needs are strictly related to the internal gains in this type of construction, so is important to use efficient lights and equipment to reduce these internal gains and is necessary to adopt "green" solutions to produce energy saving primary source.

The last analysis that has to be made is about the electrical consumption of the building. Considering that 50% of the electrical power consumed by the supermarket must be produced by renewable sources, understand this total amount is basic.

In the Table VI-3 is possible to understand the contribution of each item in terms of power requested, while the Graph VI-12 shows the contribution of each item respect to the total.

Type	Model	Power absorbed [kW]	Energy annual [kWh/unit]	Total units	Annual energy [kWh]
LED lighting	3F Quadro LED	0.11	660	170	112200
Refrigerator	Costan Granvista	-	5200	30	156000
Fridge	Constan Granbering	-	2700	12	32400
Other equipment	cash register + monitor	0.1	365	20	7300
				TOTAL [MWh]	307.9

Table VI-3: Annual electric consumptions



Graph VI-12 : Electricity needs

From the upper graph is possible to notice that the bigger part of the consumptions is occupied by the food refrigeration. This because, in supermarket, they are often completely open and exchange a lot of energy with the environment; due to this they need a lot of energy to maintain the temperature low and constant.

The building needs will be equal in all the simulation that will be carried-out in this thesis because the building model is not dependently from the type of plants.

6.2 Plants services needs

This second step is about the plants services. This type of electric consumption is the requirements for the whole plant to work and produced the heating and cooling power the building needs and it will be discussed in the chapter VII after the plant simulation.

To understand better the order of magnitude of the yearly electrical power necessary for a fan to work a first calculation has been carried out. This analysis is, obviously, a qualitative analysis just to understand the order of magnitude of the total electric power. Infact in this calculation the fan is supposed to work all the hours at the maximum rate while in the real calculation it will not and so the power consumption will be lower than this.

FAN ELECTRIC POWER NEED	
Specific unit fan power [kW/m^3/s]	0.55
Flow rate m^3/s	22.5
Fan power per units [kW/units]	12.375
Number of units	2
Total working hours per year	6200
Total electric power [kWh]	153450

Table VI-4: Fan electric power consumption

6.3 In site generation

The “In site generation” is that part of electrical energy that can be useful to reduce the total consumption because it will be used to give part of power to all the equipment of the first two category. The equipment that will be analysed to produce power from different source are the CHP, the photovoltaic panels and the solar collectors.

6.4 Dislocated generation

The last part is the energy the is not possible to produce and, obviously, has to be taken from the national network. This one has to be as lower as possible and so the plants will be design in order to keep this value down.

It’s mandatory by the standards, as said in the chapter II, that 50% of the sum of the power used to make the plant work must derive from renewable sources so it will be very important to find a good balance between the total power need, the power produced on site and the one coming from the dislocated generation.

VII. ALL AIR SYSTEM

In this Chapter will be analysed an all air system made by an air handling unit that, by definition, control both latent and sensible loads. This system is the most flexible among the four systems that will be analysed in this thesis because can be dimensioned to provide energy to the building without any power limitation. The air handling unit (from now AHU), thanks to its layout, can be used through all the season of the year because its power can be regulated to provide, to the environment, air at temperature and absolute humidity necessary to avoid discomfort condition inside the building.

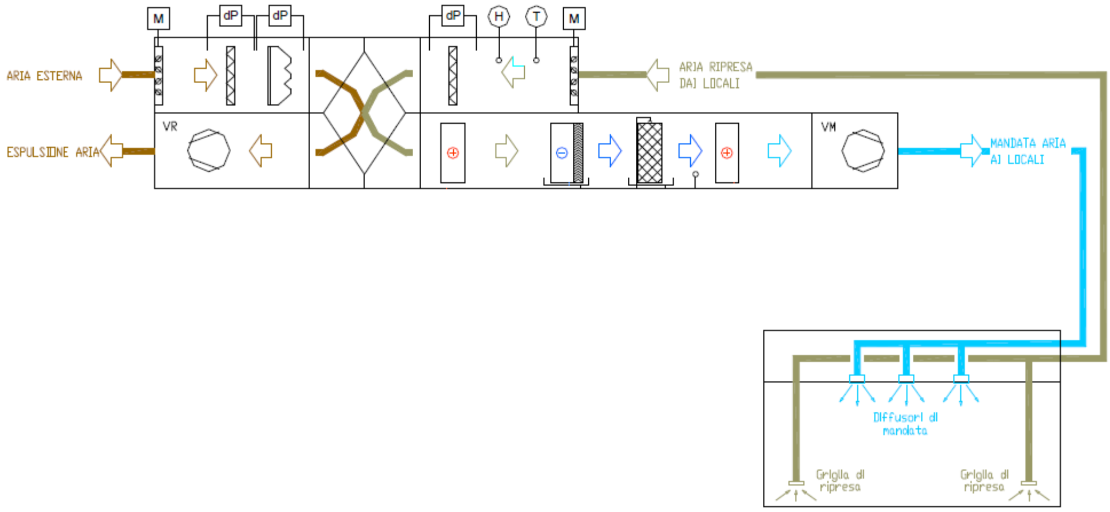


Figure VII-1 : AHU scheme

The parts of the air handling units that allow to heat and cool the air are two heating coils and one cooling coil (Figure VII-1). The process that take place into the AHU is different based on the season. Through the winter, just the two heating coils and the humidification system work inside the AHU, instead during the summer work the cooling coil and the post-heating coil. To be able to dimension the coils is necessary to access the internal loads because influence the emission air condition of the air, so the temperature and relative humidity that the air has to reach to guarantee internal comfort. Following has been analysed, separately, the summer and winter cycles that the AHU follows.

The loads used in this chapter, to calculate the power that the coils has to provide to maintain the internal comfort, are based on the results of the chapter II, where the analysis of the building carried out which are the maximum loads in the building under analysis, and also the temperature and relative humidity conditions.

The calculations are made using MATLAB [37], that is an environment for numerical calculation write in C. In MATLAB was set the energy balances that happens in the AHU, and the air conditions in the different steps of the cycles were carried out. To dimension the AHU and understand which is the suitable solution for the building under analysis, the MATLAB analysis are made with 2 different working solutions of the AHU:

- Peak load with no recirculation: this should be the worst solution in both the season, because without recirculation, the AHU, doesn't recover heat from exhaust air, so it should provide the energy itself. The peak load is used because the comfort condition must be reached along all the hours of the year
- Peak load with recirculation: differently from the previous situation in this case a portion of heat is recover from the exhaust air, so the power required to the coils should be less than the previous case.

As MATLAB input the loads found with the ideal plant simulation has been used. For what concern the volumetric flow rate have been used the following data:

- Number of people: 0,25 pers/m^2
- Volumetric flow rate for each person: 32,4 m^3/h/pers [7]
- Minimum air changes for optimal air distribution: 6 1/h
- Maximum temperature difference between emission and ambient: 10 C
  Can be justify by the height of the building, and the position of the plants on the ceiling.
- Volumetric flow rate: the volumetric flow rate of the AHU is calculated taking into account the minimum between the air changes for optimal distribution and the air changes for each person.

Below further inputs are showed specific for each season.

7.1 Summer cycle

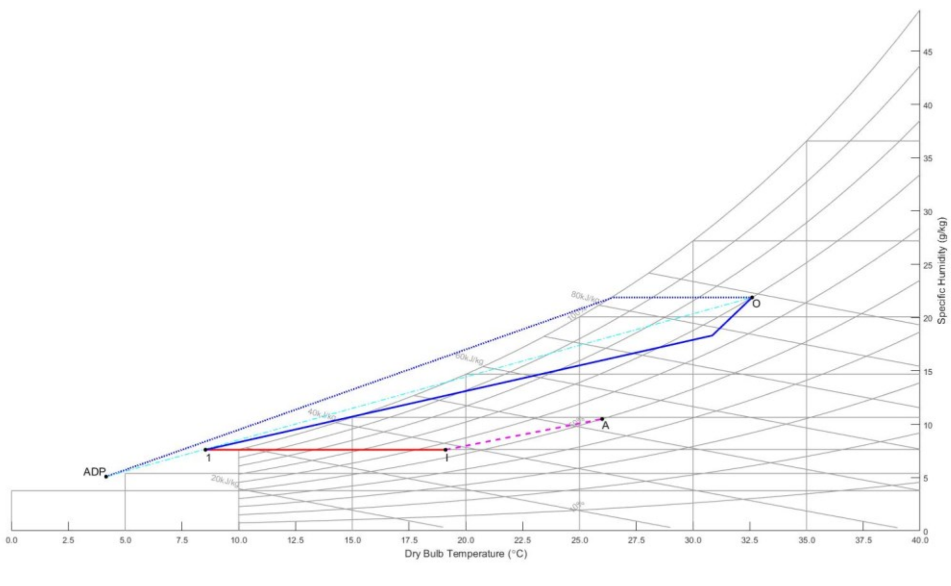
The summer period is characterized by high temperature with high absolute humidity, so the AHU cycle will be characterized by a high cooling demand but also by a dehumidification demand. The cooling coil can decrease the temperature humidify the air because when it, during the cooling process, reaches the saturation condition start to condensate so gives heat to the environment and cool down itself. After the dehumidification process the air will be post heated, because the temperature reached from the air after the passage through the cooling coil is too low to be placed in the environment directly.

To the previous input, for the summer period was added the following inputs:

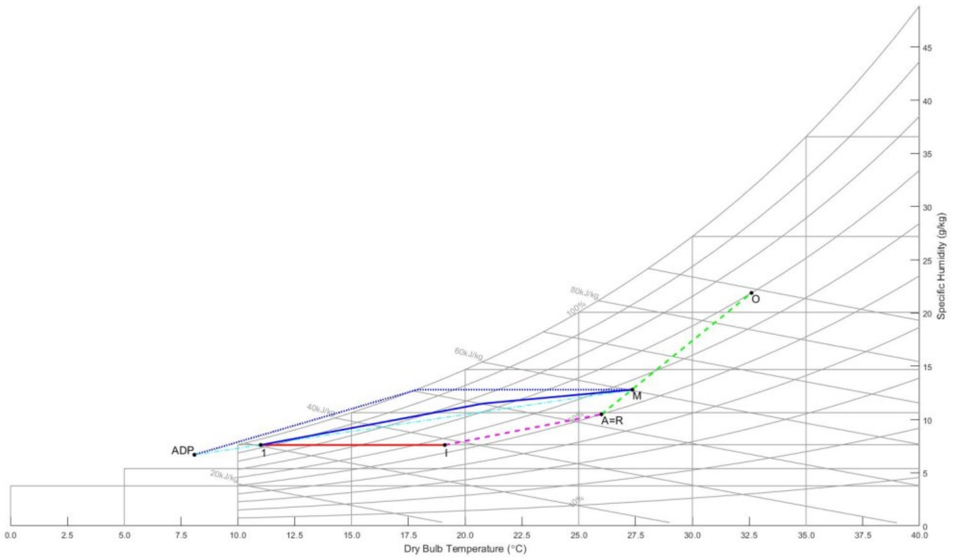
- Temperature difference for the water in the cooling coil: 5 C
- Bypass factor: 0,15. The bypass factor represent the air percentage that pass through the coil without touching it, so the percentage of air not cooled. This can be considering calculating the mixing condition between the air directly in contact with the coil and the air not in contact.

Following are showed the results of the simulation with the relative graphs:

- Maximum load, without recirculation:
  - Q heating coil: 290.80 kW
  - Q cooling coil: 1648.90 kW
- Maximum load, with recirculation:
  - Q heating coil: 222.88 kW
  - Q cooling coil: 807.27 kW



Graph VII-1 : Summer cycle without recirculation



Graph VII-2 : Summer cycle with recirculation

After the simulations can be appreciated, as thought, that recovering heat from exhaust air is possible to reduce significantly the power of the cooling and heating coil power. With the recirculation the power needed is reduced by almost 60%.

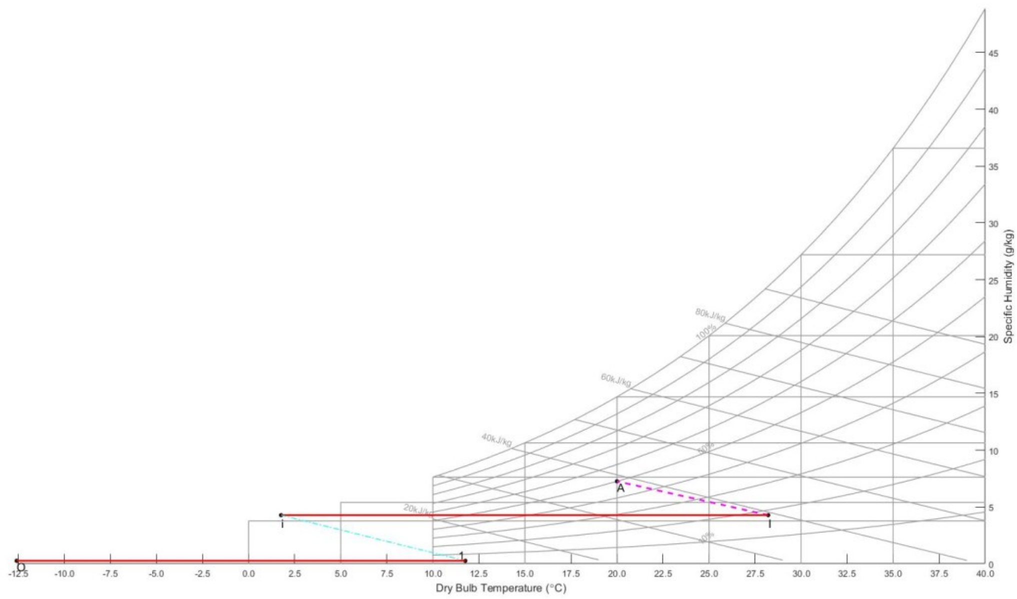
Has already said in the introduction of this chapter, a frequency analysis has been made for each season. In summer the frequency distribution (Graph VI-8, Graph VI-10) of dehumidification and cooling show that the 75% loads of both are significantly lower than the peak load used to dimension the coils. If lower powerful coils can cover most of the hours, can be better to have two (or more than two) different AHU, in order to let they work always to the max power instead to have just one AHU and regulate the power of the coils. Have two AHU, is not just more efficient in terms of temperature regulation, but makes also easier to control the coils temperature because the different AHU works almost always at the peak power, so at the same temperature of the coils. To simplify the model, in this thesis will be designed a single air handling unit because the power request to the generation subsystem will be the same independently from the AHU numbers.

7.2 Winter cycle

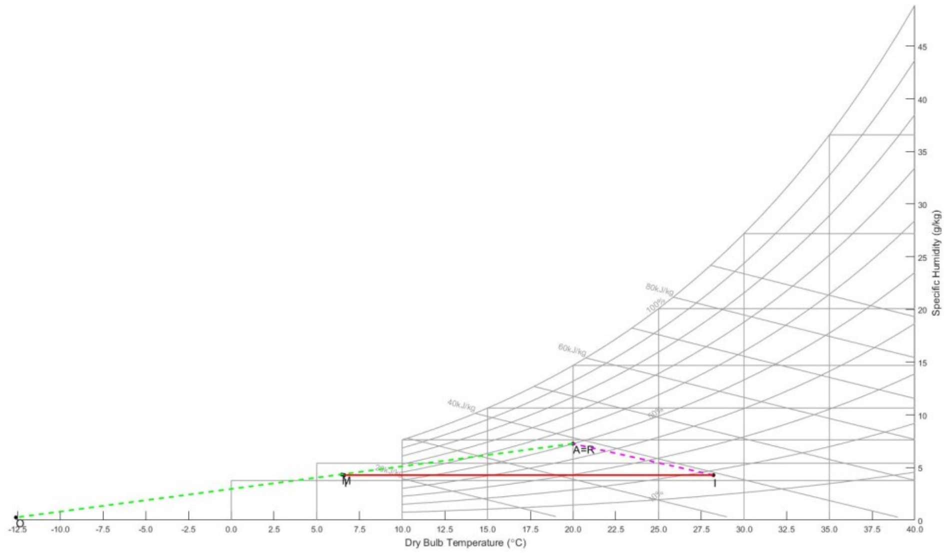
During the winter the active parts of the air handling unit are the heating coils and the humidification. Winter period in Bologna is characterised by low temperature (the minimum is -12 C) and absolute humidity. In this period is really important, as will be demonstrate, the impact on the AHU energy demand, of the recirculation. The recirculation is important because the temperature difference can be huge during the winter (almost 30°C), so recover heat from exhaust air becomes fundamental.

Below are summarised the results of the simulation with MATLAB and the corresponding graph:

- Maximum load, without recirculation:
  - Q pre-heating coil: 661.45 kW
  - Q post-heating coil: 723.31 kW
- Maximum load, with recirculation:
  - Q pre-heating coil: 0 kW
  - Q post-heating: 590.56 kW



Graph VII-3 : Winter cycle without recirculation



Graph VII-4 : Winter cycle with recirculation

As hypothesized, in winter the recirculation has a huge influence in the energy demand. Talking about percentage, the post-hating coils reduced its energy demand by almost 25%, instead, as can be appreciated from the Graph VII-4, the pre-heating coil will be unused, this mean that the energy demand is reduced by 1000 kW, just applying a passive strategy inside the air handling unit.

VIII. BASELINE PLANT

The baseline plant chapter is based on a simulation made to better understand the differences between the old Italian regulation and the new one. According to the old regulation the building plants installed on a building must cover with renewable energy just the 50% of the domestic hot water use, so the thermal and electric plants was limitless for what concern the use of non-renewable energy to produce heat and electricity. The baseline model (Figure VIII-1) is composed by an all-air system and as generation subsystem is present an electric chiller to produce chilled water needed by the AHU cooling coil and a boiler to produce hot water needed by the post-heating coil and for domestic hot water. All the in-site generation systems are connected to the national network so it will be expected that the plants will not respect the requirements given by the new standards.

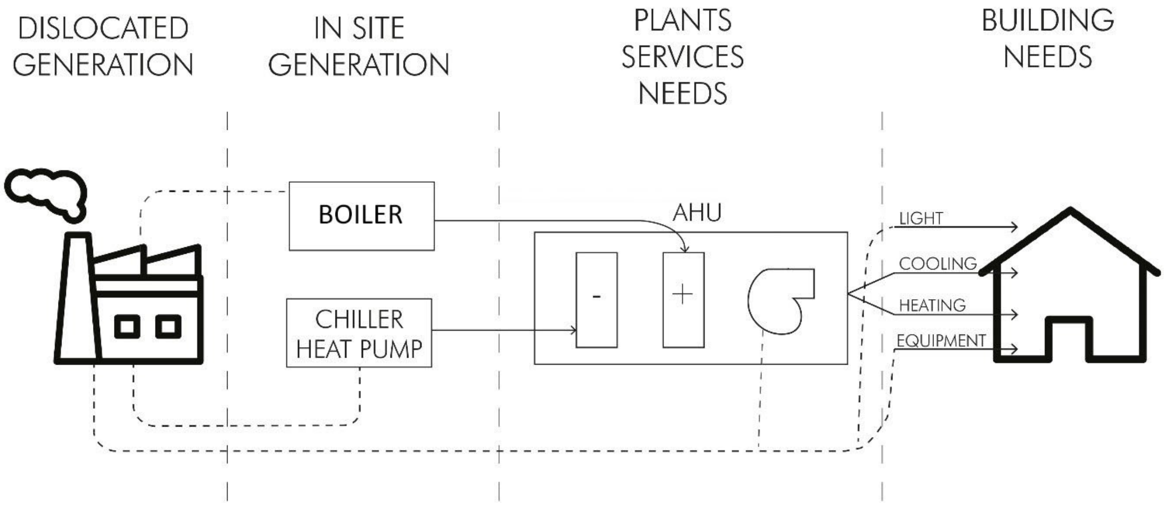


Figure VIII-1 : Baseline plant scheme

The plant was modelled in trnsys [34] starting from the model used to calculate the building energy needs. The workflow and the input assigned can be divided in three different parts. Below are listed all the inputs used for the calculation:

- Air handling unit: to model the AHU the year has been divided into two seasons as analysed in the previous chapter. The two different seasons have been modelled following the mathematical model defined in matlab but using trnsys.

  The two main parameters that are used as input for both the cycles are:
    - Air flow rate: 81000 kg/hr
    - Design fan power: 12.3 kW, derived from datasheet

- Boiler: the boiler loop in trnsys is connected to the energy need by the post-heating coil and then in composed by four different elements that are a calculator in which are defined the parameters, a water buffer, a pump and the boiler. All the parameters are calculated automatically by the calculator and no one input is defined by the user.

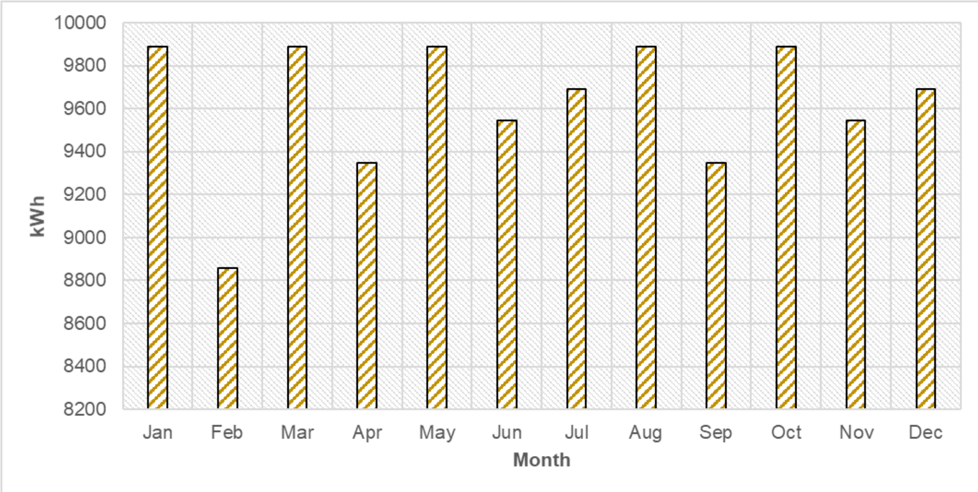
- Electric chiller pump: The energy required to the chiller is the one needed by the cooling coil during the summer period to cool down and dehumidification the air. So the electric chiller pump take as input the energy needs of the cooling coil and similarly to the boiler loop, carry out the consumption. The difference between the consumption of the boiler and the chiller is that the boiler work with a fuel, instead the chiller require electric energy

As already said, the building needs are independently from the plants, so can be considered constant in all the simulations. The building needs are showed in Graph VI-4. Following are showed the results of the simulation for the other parts of the plant.

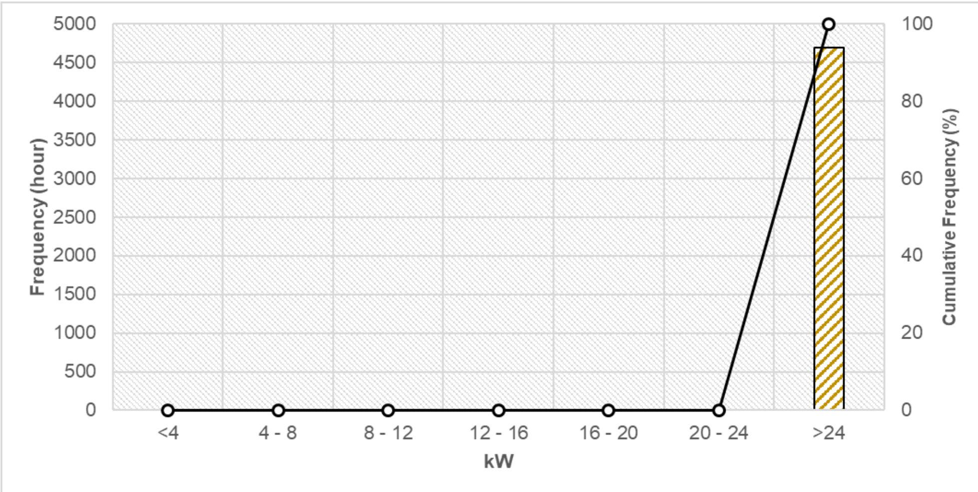
8.1 Plants services needs

As plants services needs there is three different energy inputs request to the AHU to produce the inlet air:

- Electric energy requested to the fan: In the AHU is possible to find two fans, one to let the air flow through the environment, and one to suck the exhaust air from the internal environment. The electric energy needed by the fans was calculated using trnsys, following are showed the monthly electric energy requested by these systems and the frequency at which the energy is requested.



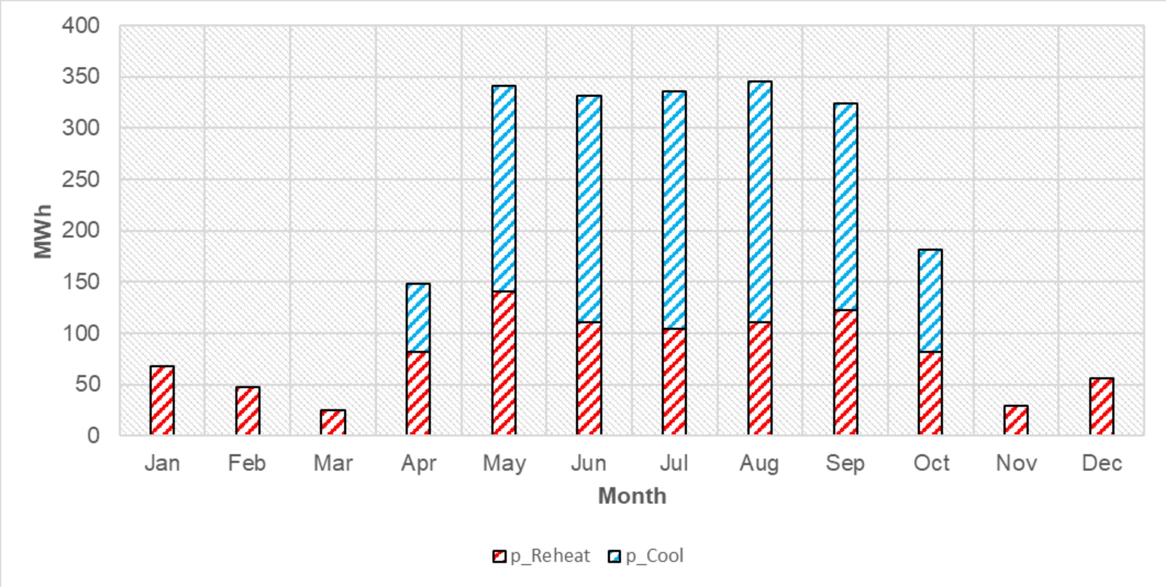
Graph VIII-1: Fan power consumption



Graph VIII-2: Fan power frequency

As shown in the graphs above the power consumption is constant during the year as expected. Looking at the frequency graph is possible to notice that the fan works all year long at full power.

- In the following graph and table are shown the energy requested by the AHU to balance the loads and maintain the perfect condition inside the supermarket. As already seen in the Graph VI-4 the heating part is higher, and this is due ventilation that decreases the temperature inside the building that needs to heat up in the morning when the plant starts working.

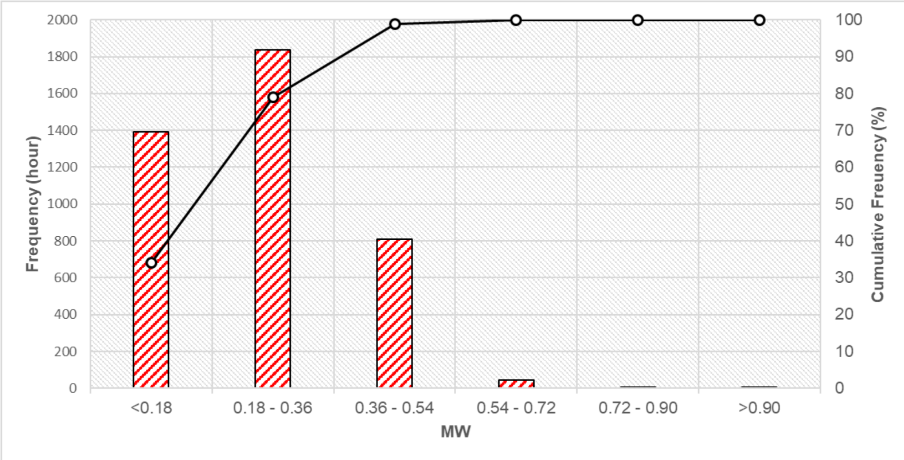


Graph VIII-3: Total post-heating and cooling coil energy need

Month		p_Reheat	p_Cool
Jan	1	67.87	0.00
Feb	2	47.35	0.00
Mar	3	25.41	0.00
Apr	4	81.74	66.92
May	5	140.69	199.88
Jun	6	110.14	221.17
Jul	7	104.59	230.69
Aug	8	110.41	235.41
Sep	9	122.62	201.69
Oct	10	81.57	99.51
Nov	11	29.31	0.00
Dec	12	56.20	0.00
TOTAL		**977.91**	**1255.27**

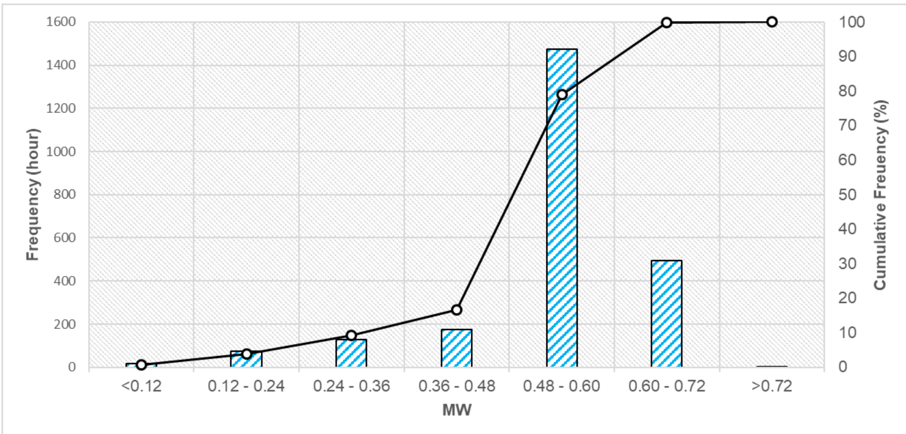
Table VIII-1: Post-heating and cooling battery energy needs

Hot water requested by the post-heating coil: In the system under analysis there is only the post-heating coil, because, as analysed in the previous chapter, with recirculation the pre-heating coil is unused in both summer and winter. The hot water frequency power by the system was analysed using trnsys and the results are showed below in Graph VIII-4.



Graph VIII-4: Post heating coil frequency power

- Cold water requested by the cooling coil: The cooling coil is the only one part of the system that require chilled water to work, so the dimension of the electric chiller pump is directly affected by the energy needs of the cooling coil. The results of the simulation with trnsys are showed in Graph VIII-5. Studying the frequency and finding its peak is possible to design the chiller that will be used in the system.

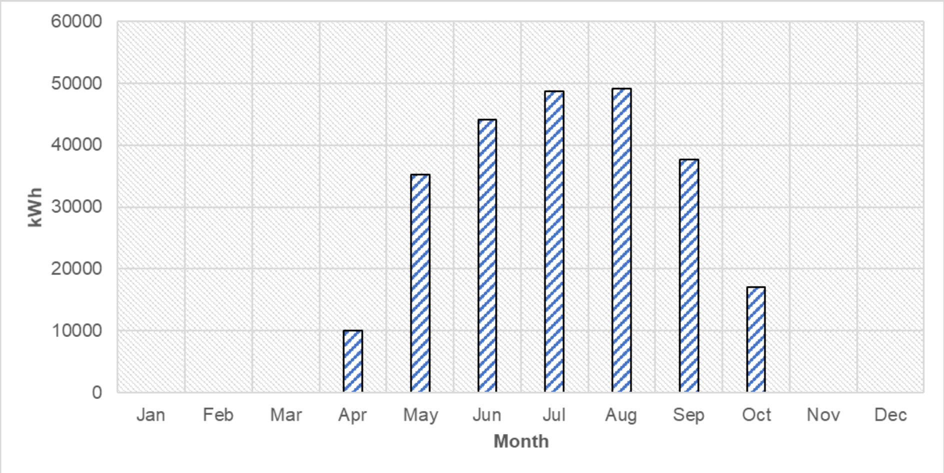


Graph VIII-5: Cooling coil frequency power

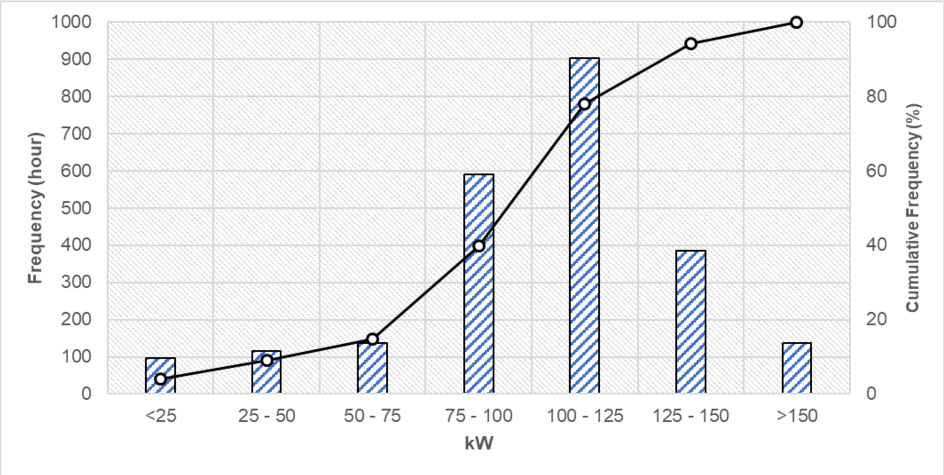
8.2 In site generation

As in-site generation, in this case, can be found an electric chiller, to produce the chilled water, and a boiler that produce hot water. These two technologies work with two different energy vectors; the chiller with the electricity and the boiler with fuel, generally fossil.

The Graph VIII-6 shows the energy that the chiller requires all year long while, the Graph VIII-7, shows the frequency of the power at which the chiller works. This graph is the most important because it's possible to understand that the peak power is 179.3 kW and so will be choose a chiller that have at least this power.

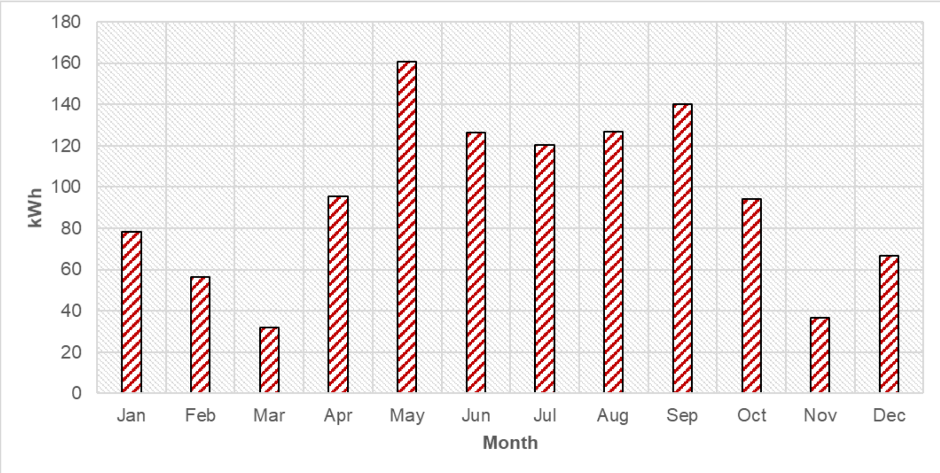


Graph VIII-6: Chiller energy need

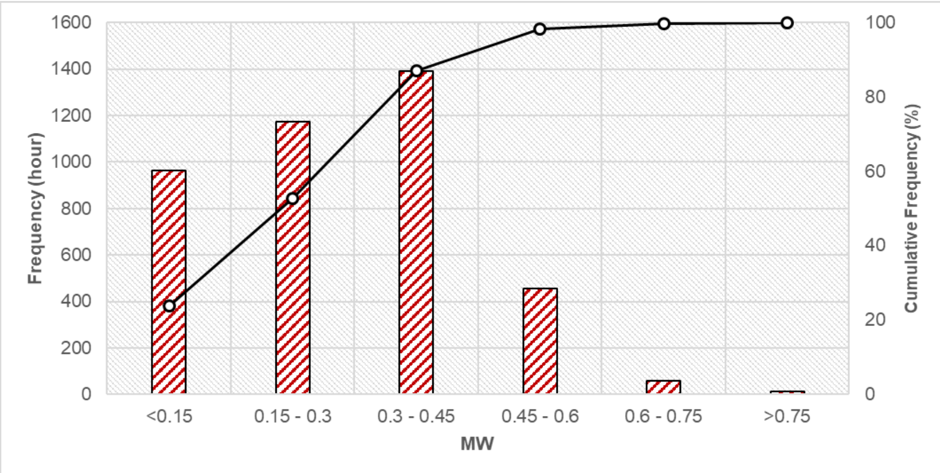


Graph VIII-7: Chiller power frequency

Instead for the boiler has been computed the energy that the fuel must produce to satisfy the hot water needs. The Graph VIII-8 shows the energy that the boiler requires all year long while, the Graph VIII-9, shows the frequency of the power at which the boiler works. This graph is the most important because it's possible to understand that the peak power is 1.06 MW but the boiler needs this power only for 7 hours during the year it will be more reasonable to choose a boiler with a power of 500kW.



Graph VIII-8: Boiler energy need



Graph VIII-9: Boiler power frequency

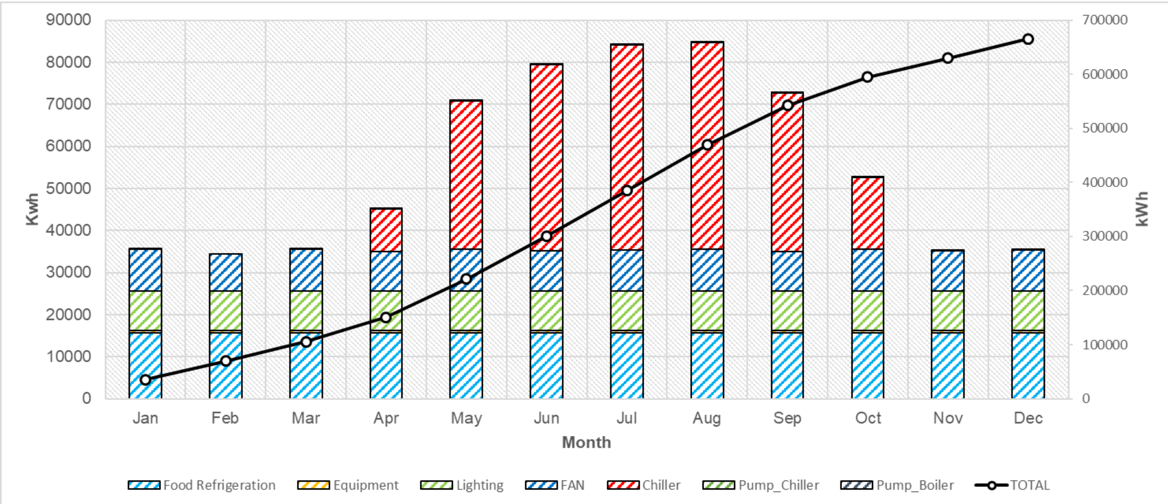
8.3 Dislocated generation

At the end of the analysis, the energy needed form a dislocated source can be computed. According to the system analysed in this chapter as baseline, the types of energy that must be bought from the national network are two:

- The electric energy needed in the three different phases of the air conditioning cycle are summarized in the table below.

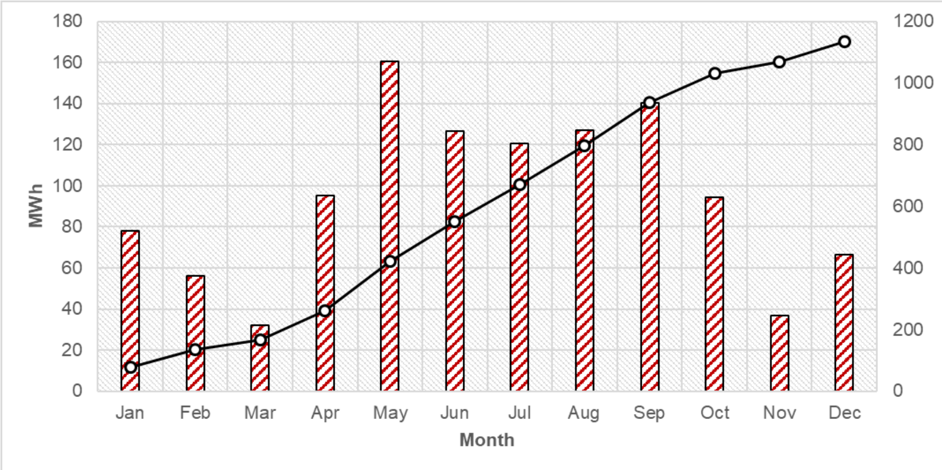
Month		Food refrigeration	Equipment	Light	Fan	Chiller	Chiller pump	Boiler pump	TOTAL (kWh)
Jan	1	15700	608.3	9350	9899.28	0.00	0.00	0.03	35547.63
Feb	2	15700	608.3	9350	8856.07	0.00	0.00	0.02	70062.05
Mar	3	15700	-608.3	9350	9899.28	0.00	0.00	0.01	105609.67
Apr	4	15700	-608.3	9350	9348.07	10122.43	0.11	0.05	150738.66
May	5	15700	-608.3	9350	9889.28	35182.19	0.41	0.07	221468.94
Jun	6	15700	-608.3	9350	9544.88	44118.96	0.5	0.05	300791.65
Jul	7	15700	-608.3	9350	9692.48	48684.87	0.53	0.04	384827.91
Aug	8	15700	-608.3	9350	9889.28	49146.55	0.55	0.04	469522.66
Sep	9	15700	-608.3	9350	9348.07	37666.60	0.43	0.06	542196.16
Oct	10	15700	-608.3	9350	9889.28	17081.95	0.2	0.04	594825.96
Nov	11	15700	-608.3	9350	9544.88	0.00	0.00	0.01	630029.18
Dec	12	15700	-608.3	9350	9692.48	0.00	0.00	0.02	**665380.01**
TOTAL		188400	7300	112200	115473.32	242003.55	2.73	0.42	

Table VIII-2: Monthly and total electric consumption



Graph VIII-10: Monthly and total electric consumption

- The gas needed from the boiler to produce the hot water needed by the post-heating coil is about 1134 MWh.



Graph VIII-11: Monthly and total gas consumption

As said in previous chapters, to satisfy the new Italian regulation, the plants must use at least 50% of renewable energy to satisfy internal comfort. To calculate the percentage of renewable energy used, the code provides the Table II-1, in which can be found the portion of renewable energy based on the energy vector type. In the case analyzed in this chapter, the two energy vectors used are the electricity from the net and the fuel used by the boiler. The electricity took from the national network, has a ratio of 0,47/2,42 of renewable energy used, instead the fuel has a 100% ratio of non-renewable energy used.

Type	Type of vector	Quantity (kWh)	Primary Energy	Renewable energy	Non Renewable energy
Fridges	Electricity national network	188400	455928	91185.6	364742.4
Equipment	Electricity national network	7300	17666	3533.2	14132.8
Lighting	Electricity national network	112200	271524	54304.8	217219.2
FAN	Electricity national network	115473.32	279445.4272	55889.08544	223556.3418
Chiller	Electricity national network	242003.55	585648.5963	117129.7193	468518.8771
Chiller pump	Electricity national network	2.73	6.595199973	1.319039995	5.276159978
Boiler pump	Electricity national network	0.42	1.02042757	0.204085514	0.816342056
Boiler	Gas national network	1134274.51	1190988.232	0	1190988.232
TOTAL			Renewable energy	Non renewable energy	% Renewable energy
			322044	2479164	11.50

Table VIII-3: Renewable energy summary

As it's possible to notice from the Table VIII-3 the percentage of renewable energy is 11.5% and this is not acceptable by the actual standards.

In the next chapter will be discussed another solution for the plant in order to reach at least 50% of renewable primary energy.

IX. HEAT PUMP + PHOTOVOLTAIC PANELS

This chapter is about a plant that includes a heat pump instead of the boiler seen before and a system of photovoltaic panels installed on the supermarket roof. The aim is to get as close as possible to the goal of 50% of primary energy coming from renewable sources. This is the first step towards it and maybe it won't be the final solution but is important to understand how much electrical energy can be produced from the PV system, if it's enough to meet the standard or it must be supported by other equipment that can produce thermal and electric energy at the same time (CHPs).

The whole model (Figure IX-1) is composed by an all-air system and as generation subsystem is present an electric chiller to produce chilled water needed by the AHU cooling coil and an heat pump to produce hot water needed by the post-heating coil and for domestic hot water. All the in-site generation systems are connected to the national network that is helped by the PV panels as said before.

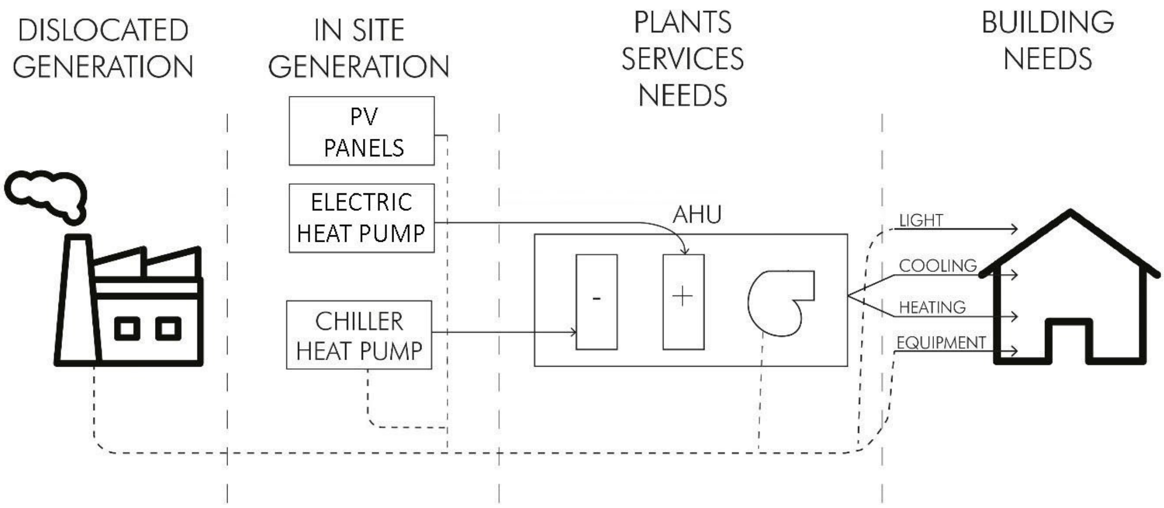
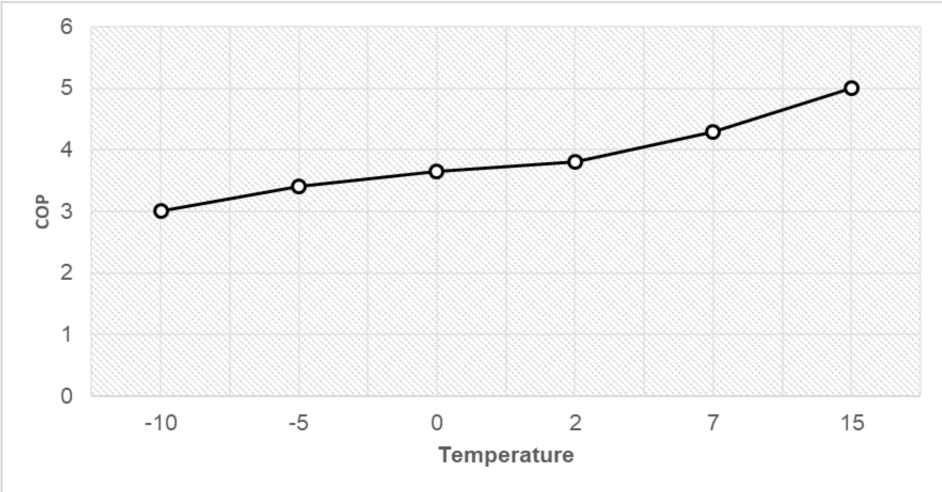


Figure IX-1: HP + PV plant scheme

The difference, in the trnsys model, between this case and the baseline case is the presence of a heat pump to produced heated water, instead of the boiler. The input used for the trnsys model are the same of the baseline, a part of the heat pump.

The heat pump in trnsys is connected to the energy need by the post-heating coil and then connected to a calculator in which are defined the parameters and the formula that carry out its electric consumption. Also in this case is present a pump that let the water flows in the circuit.

The performance map used for the heat pump type in trnsys is the following one [14].



Graph IX-1: Heat pump performance map

As already said, the building needs are independently from the plants, so can be considered constant in all the simulations. The building needs are showed in Graph VI-4. Following are showed the results of the simulation for the other parts of the plant.

9.1 Plants services needs

As plants services needs there is three different energy inputs request to the AHU to produce the inlet air:

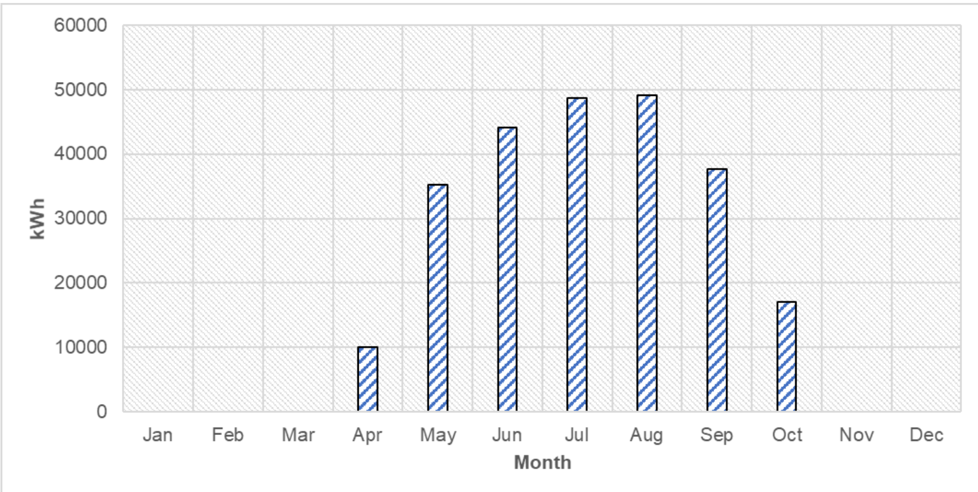
- Electric energy requested to the fan: In the AHU is possible to find two fans, one to let the air flow through the environment, and one to suck the exhaust air from the internal environment. The electric energy needed by the fans was calculated using trnsys, following are showed the monthly electric energy requested by these systems and the frequency at which the energy is requested.

  The power consumption is constant during the year as expected and is equal to the one seen in the baseline (Graph VIII-1). Looking at the frequency graph is possible to notice that the fan works all year long at full power.

- Post-heating and cooling coil energy need: the energy requested by the AHU to balance the loads and maintain the perfect condition inside the supermarket. As the AHU is the same of the baseline, the energy needs don't change and are the same show in the Graph VIII-3 and Table VIII-1.

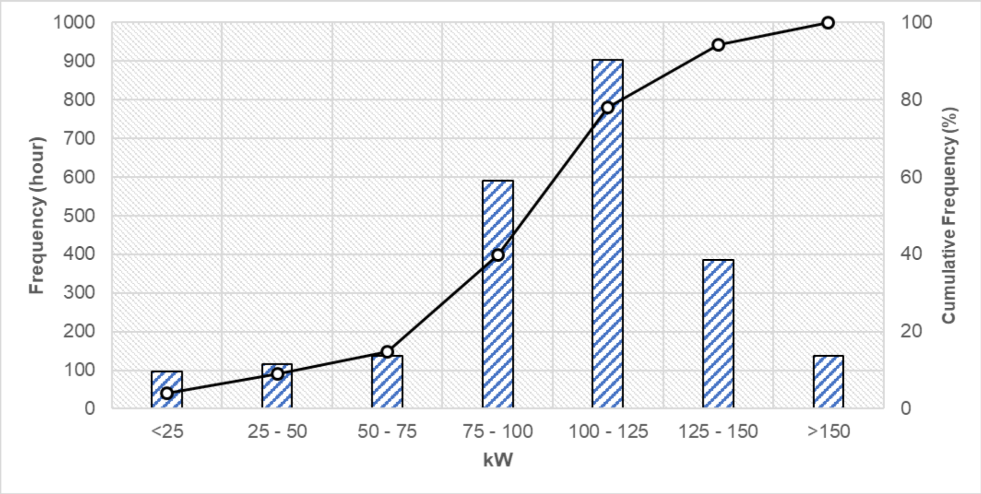
9.2 In site generation

As in-site generation, in this case, can be found an electric chiller, to produce the chilled water, and an electric heat pump (water-air heat pump) that produce hot water. These two technologies work with the same energy vectors that is electricity. The Graph IX-2 shows the energy that the chiller requires all year long while, the Graph IX-3, shows the frequency of the power at which the chiller works. This graph is the most important because it's possible to understand that the peak power is 179.3 kW and so will be choose a chiller that have at least this power.

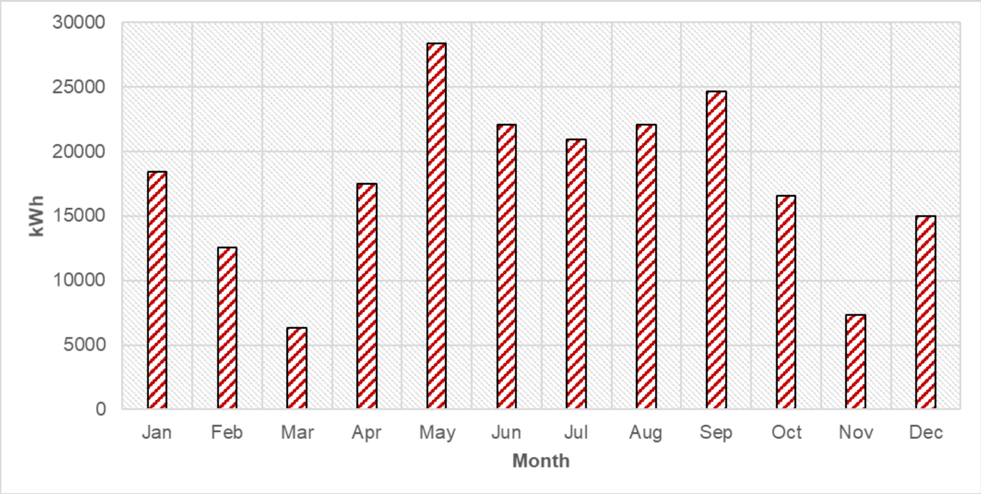


Graph IX-2: Chiller energy need

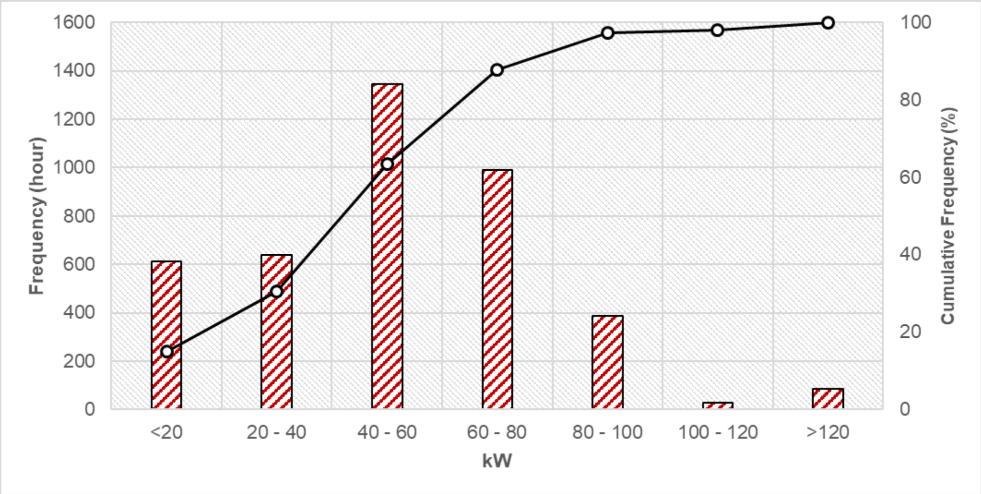
Instead for the heat pump has been computed the energy that the machine must produce to satisfy the hot water needs. The Graph IX-4 shows the energy that the heat pump requires all year long while, the Graph IX-5, shows the frequency of the power at which the boiler works. This graph is the most important because it's possible to understand that the peak power is 320 kW but the heat pump needs this power only for 6 hours during the year it will be more reasonable to choose a machine with a power of 100 kW.



Graph IX-3: Chiller power frequency



Graph IX-4: Heat pump energy need



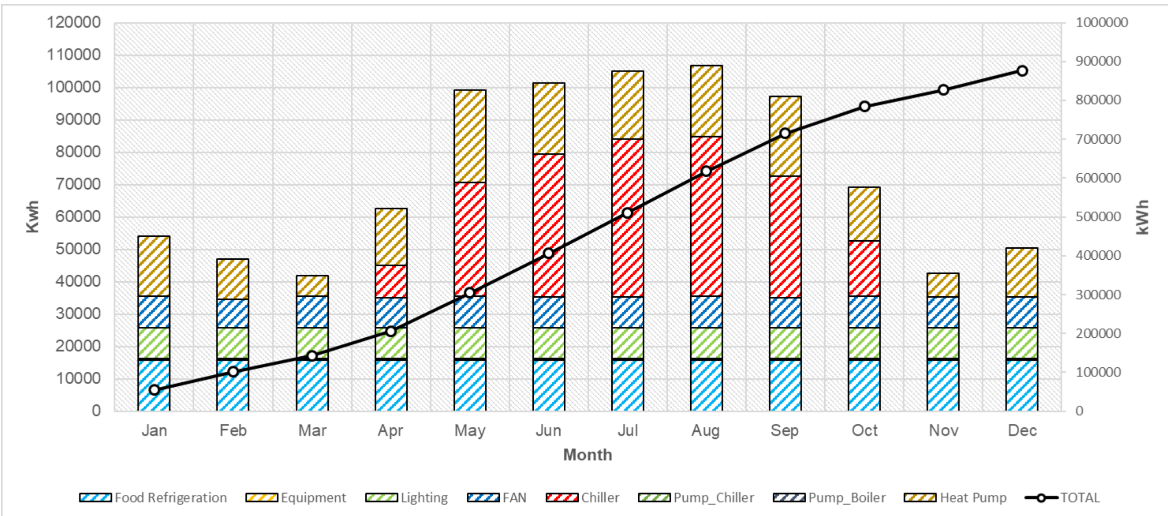
Graph IX-5: Heat pump power frequency

9.3 Dislocated generation

At the end of the analysis, the energy needed form a dislocated source can be computed. The electric energy needed in the three different phases of the air conditioning cycle are summarized in the table below.

Month		Food refrigeration	Equipment	Light	Fan	Chiller + heat pump	Chiller pump	Boiler pump	TOTAL (kWh)
Jan	1	15700	608.3	9350	9899.28	18449.01	0.00	0.04	53996.7
Feb	2	15700	608.3	9350	8856.07	12531.81	0.00	0.02	101042.9
Mar	3	15700	608.3	9350	9899.28	6317.91	0.00	0.01	142908.4
Apr	4	15700	608.3	9350	9348.07	27630.41	0.11	0.07	205545.4
May	5	15700	608.3	9350	9889.28	63521.49	0.41	0.11	304615.0
Jun	6	15700	608.3	9350	9544.88	66148.12	0.5	0.07	405966.9
Jul	7	15700	608.3	9350	9692.48	69604.25	0.53	0.06	510922.6
Aug	8	15700	608.3	9350	9889.28	71239.8	0.55	0.07	617710.6
Sep	9	15700	608.3	9350	9348.07	62275.5	0.43	0.09	71499.3
Oct	10	15700	608.3	9350	9889.28	33662.32	0.2	0.06	784203.2
Nov	11	15700	608.3	9350	9544.88	7298.76	0.00	0.01	826705.2
Dec	12	15700	608.3	9350	9692.48	14978.3	0.00	0.03	**877034.3**
TOTAL		188400	7300	112200	115473.32	453657	2.73	0.63	

Table IX-1: Monthly and total electric consumption

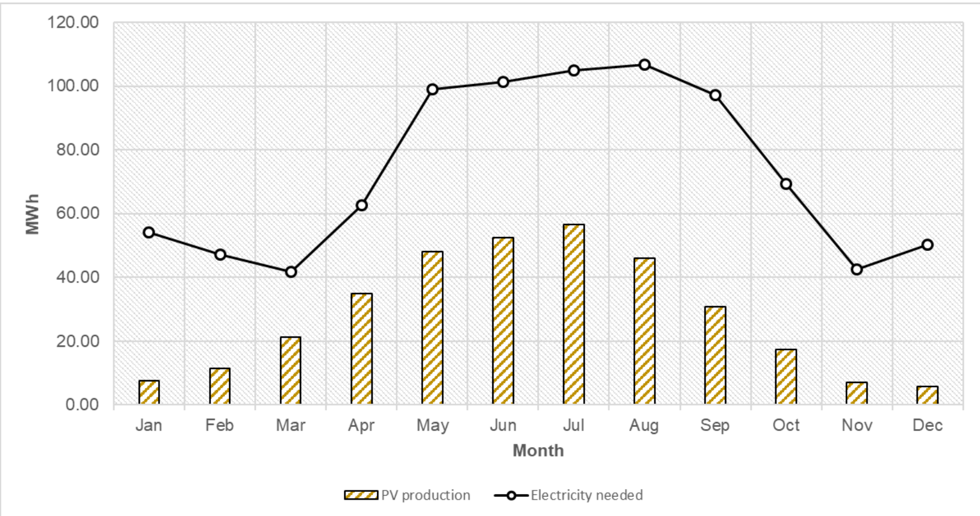


Graph IX-6: Monthly and total electric consumption

In the Table IX-2 and Graph IX-7 is possible to notice the yearly production of electricity by the photovoltaic panels. Obviously in the summer months the collectors are able to produce more energy, but the total needs of the supermarket are always higher than the electricity produce so in every month and season part of the energy will be taken from the national network.

Month		PV production	Electricity needed
Jan	1	7.59	53.9
Feb	2	11.39	47.0
Mar	3	21.28	41.8
Apr	4	35.03	62.6
May	5	48.12	99.0
Jun	6	52.41	101.3
Jul	7	56.51	104.9
Aug	8	45.88	106.7
Sep	9	30.77	97.2
Oct	10	17.41	69.2
Nov	11	7.20	42.5
Dec	12	5.82	50.3

Table IX-2: Yearly electricity production from PV panels



Graph IX-7: Electricity produced by PV vs electricity needs

As said in previous chapters, to satisfy the new Italian regulation, the plants must use at least 50% of renewable energy to satisfy internal comfort. To calculate the percentage of renewable energy used the code provide the Table II-1, in which can be found the portion of renewable energy based on the energy vector type. In the case analyzed in this chapter, the two energy vectors used are the electricity from the net and the fuel used by the boiler. The electricity took from the national network, has a ratio of 0,47/2,42 of renewable energy used, instead the electricity produced by the PV has a 100% ratio of renewable energy used.

Moreover, as said in the Chapter 2.2.2, part of the primary energy of the heat pump can be considered as renewable using the equations Equation II-2 and Equation II-3 (Table IX-3) [1]. This because the heat pump uses the environment air to work and it can be considered as a renewable energy vector by the standard.

Epdc (kWh/year)	977915.0
Ep,pdc (kWh/year)	512202.9
SPF (-)	1.9
ERES (kWh/year)	465712.1

Table IX-3: Renewable energy from heat pump

Summarizing what has been said, it's possible to notice from the Table IX-4 and Table IX-5 that the percentage of renewable energy is 50.58% and this is acceptable by the actual standards.

Type	Type of vector	Quantity (kWh)
Fridges	Electricity national network	188400
Equipment	Electricity national network	7300
Lighting	Electricity national network	112200
FAN	Electricity national network	115473.32
Chiller	Electricity national network	242003.55
Heat pump	Electricity national network	211654.11
Chiller pump	Electricity national network	2.73
Boiler pump	Electricity national network	0.63
PV panel	Energy Produced	339418.76

Table IX-4: Total energy summary

RENEWABLE ENERGY CALCUALTION		Primary renewable	Primary non renewable	% renewable energy
Total amount from network (kWh/year)	537615.58	260206	1040824	50.58
Total amount from PV (kWh/year)	339418.76	339418.76	0	
Total amount from HP (kWh/year)	211654.11	465712.1	0	

Table IX-5: Renewable energy summary

The final result is obviously better than the one obtained before, but the aim is to go deeper and try different types of generators. In the following chapter a further step will be done adding a CHP to the system still using the heat pump and the photovoltaic panel. The aim will be to reduce the total consumption of electricity from the net and increase a bit more the percentage of renewable energy.

X. HEAT PUMP + CHP

This chapter is about a plant that includes a CHP and the heat pump seen before. The aim is to get as close as possible to the goal of 50% of primary energy coming from renewable sources. The CHP is a good solution to reach both the 50% of renewable energy and to meet the gains that the building has.

This machine has the peculiarity to produce heat and electricity at the same time but it’s an internal combustion engine so it uses a big amount of gas to work properly. In order not to have a too big CHP the decision was to choose it so that it could cover almost completely the electricity need of the building and, regarding the heat production, it is flanked by an heat pump that works only when the heat load is higher than the one that the CHP is able to produce.

This is a good choice because, as seen in the previous chapter, part of the energy used by the heat pump can be considered as renewable by the standard.

The whole model (Figure X-1) is composed by an all-air system and as generation subsystem is present an electric chiller to produce chilled water needed by the AHU cooling coil, a CHP and a heat pump to produce hot water needed by the post-heating coil. All the in-site generation systems are connected to the national network both for electricity and gas.

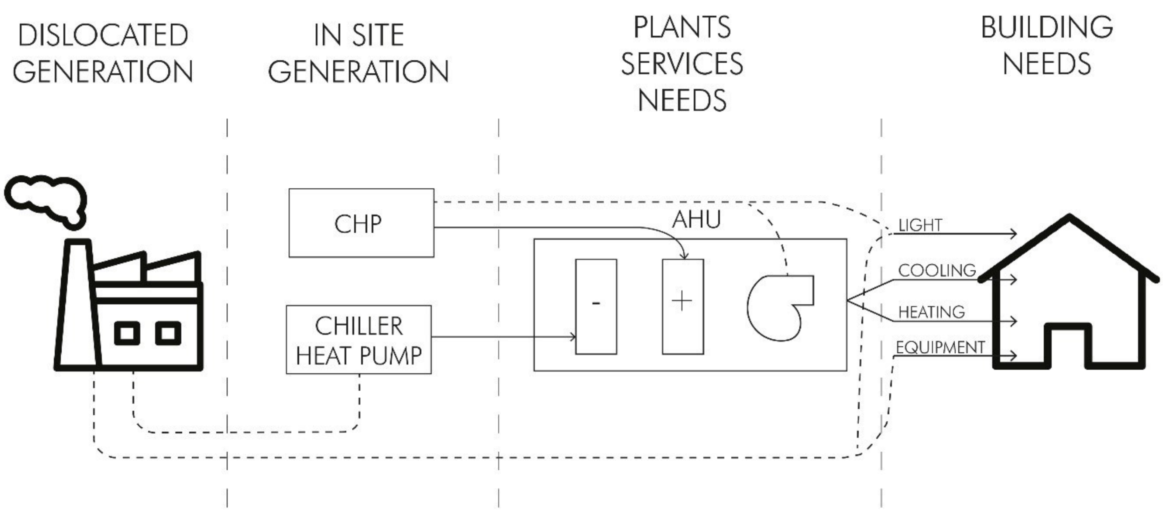


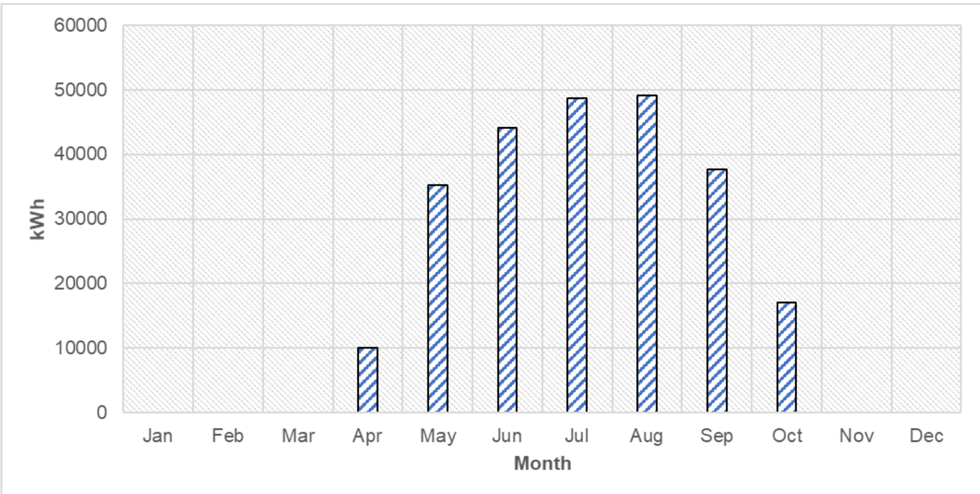
Figure X-1: HP + CHP plant scheme

As already said, the building needs are independently from the plants, so can be considered constant in all the simulations. The building needs are showed in Graph VI-4. Below are showed the results of the simulation for the other parts of the plant. In this case study the plants services needs are the same of the previous 2 cases so they are not re-described. For any information about it the chapter 9.1 can be consulted.

10.1 In site generation

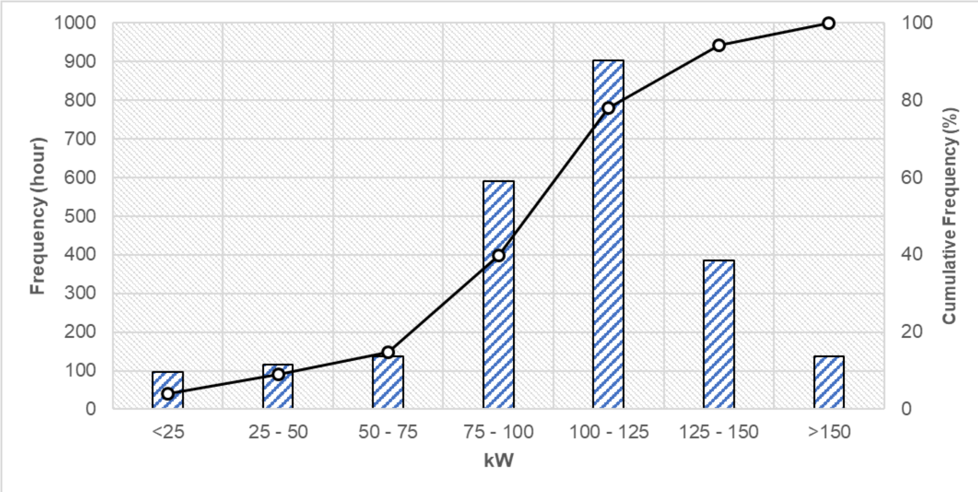
As in-site generation, in this case, can be found an electric chiller, to produce the chilled water, and an electric heat pump (water-air heat pump) and a CHP that produce hot water.

The Graph X-1 shows the energy that the chiller requires all year long while, the Graph X-2, shows the frequency of the power at which the chiller works. This graph is the most important because it's possible to understand that the peak power is 179.3 kW and so will be choose a chiller that have at least this power.



Graph X-1: Chiller energy need

The following table (Table X-1) and graph (Graph X-3) show the monthly and yearly thermal and electric production of the CHP respect to the gas energy consumption. The Italian standard and also the regional one establishes that the CHP must have a PES (primary energy saving) higher than 0.2 and the bigger part of the CHPs present nowadays on the market respect this parameter that in this case is 0.20.

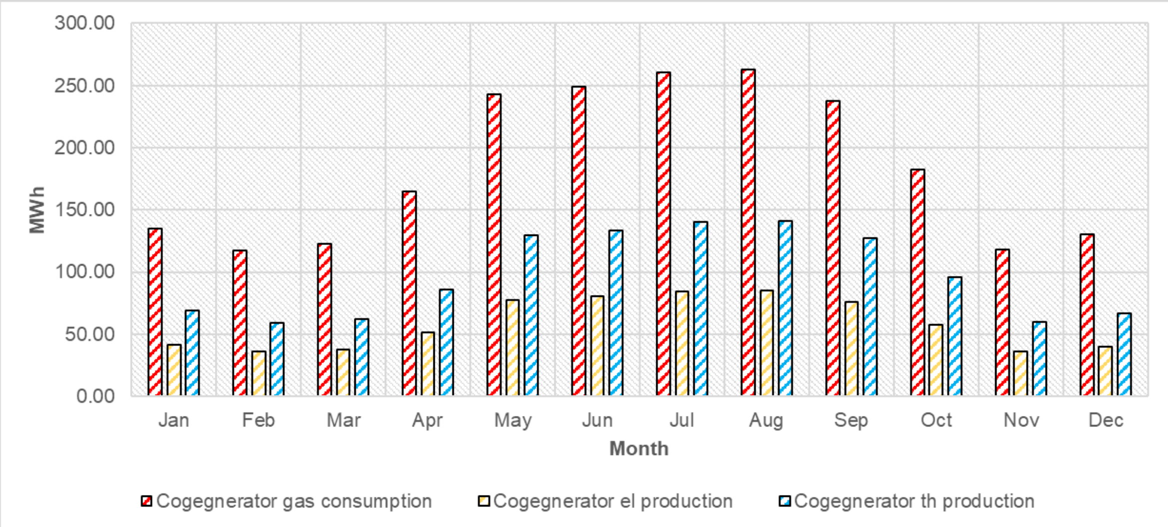


Graph X-2: Chiller power frequency

Month		Cogegnerator gas consumption	Cogegnerator electric production	Cogegnerator thermal production
Jan	1	135.26	41.75	68.76
Feb	2	117.21	36.14	59.49
Mar	3	122.48	37.72	62.02
Apr	4	164.94	51.66	85.73
May	5	242.96	77.68	129.44
Jun	6	248.72	80.27	133.29
Jul	7	260.69	84.49	139.99
Aug	8	263.12	85.24	141.28
Sep	9	237.81	76.33	126.98
Oct	10	182.57	57.65	95.64
Nov	11	118.46	36.48	59.97
Dec	12	130.75	40.37	66.46
TOTAL		**2224.97**	**705.78**	**1169.05**

Table X-1: CHP yearly production and consumption

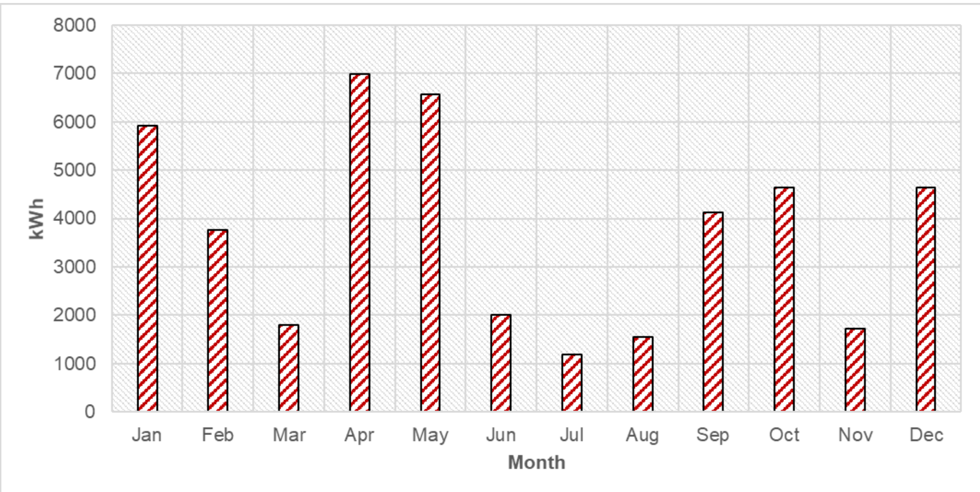
Instead for the heat pump has been computed the energy that the machine must produce to cover the loads that the CHP isn't able to. The Graph X-4 shows the energy that the heat pump requires all year long while, the Graph X-5, shows the frequency of the power at which the boiler works. This graph is the most important because it's possible to understand that the peak power is 209 kW but the heat pump needs this power only for few hours during the year it will be more reasonable to choose a machine with a power of 60 kW.



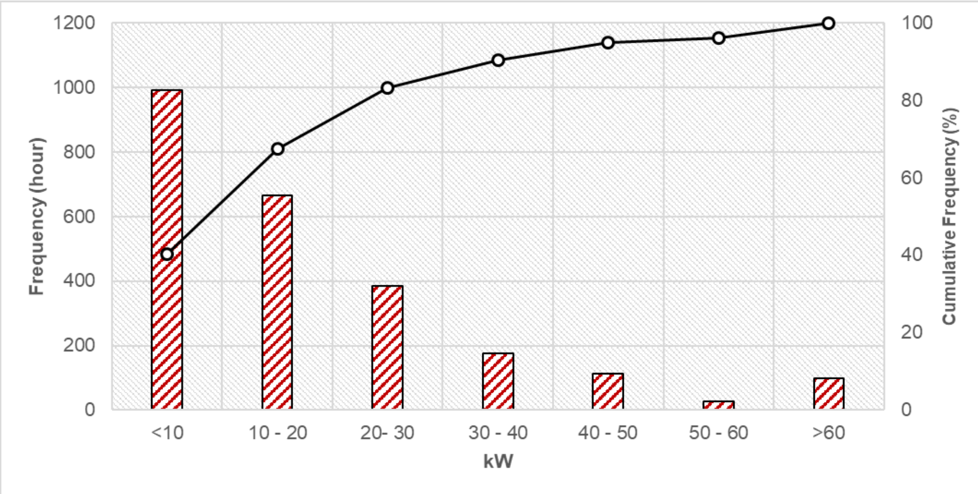
Graph X-3: CHP yearly production and consumption.

CHPHη	0.525
CHPEη	0.317
RefHη	0.81
RefEη	0.51
PES	**0.20**

Table X-2: PES calculation



Graph X-4: Heat pump energy need



Graph X-5: Heat pump power frequency

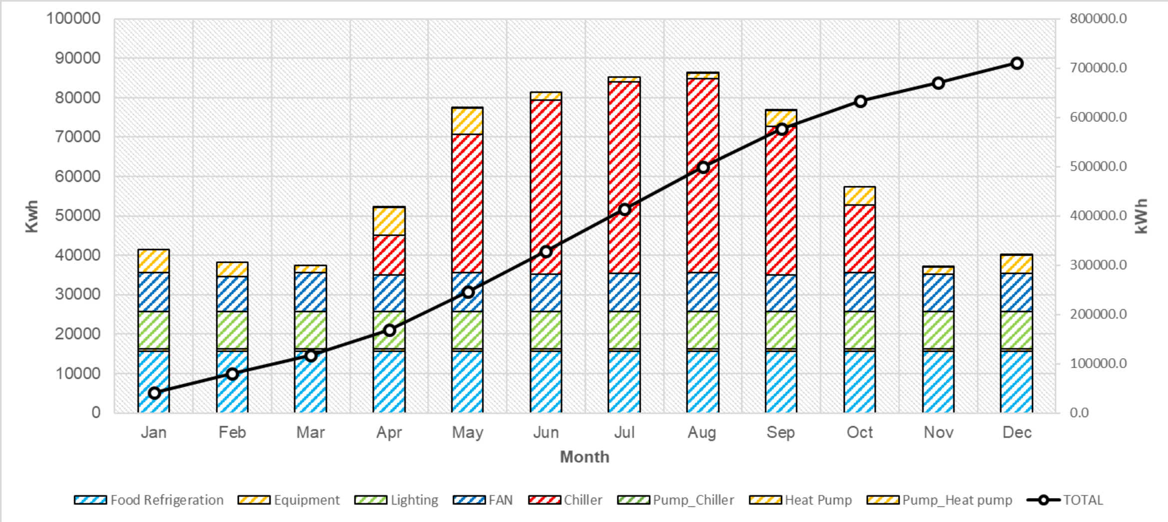
10.2 Dislocated generation

At the end of the analysis, the energy needed form a dislocated source can be computed. According to the system analysed in this chapter as baseline, the types of energy that must be bought from the national network are two:

- The electric energy needed in the three different phases of the air conditioning cycle are summarized in the table below.

Month		Food refrigeration	Equipment	Light	Fan	Chiller + heat pump	Chiller pump	HP pump	TOTAL (kWh)
Jan	1	15700	608.3	9350	9899.28	5920.21	0.00	0.01	41467.8
Feb	2	15700	608.3	9350	8856.07	3767.17	0.00	0.01	79749.4
Mar	3	15700	608.3	9350	9899.28	1791.04	0.00	0.00	117088.1
Apr	4	15700	608.3	9350	9348.07	17113.68	0.11	0.02	169208.3
May	5	15700	608.3	9350	9889.28	41746.03	0.41	0.01	246502.3
Jun	6	15700	608.3	9350	9544.88	46118.23	0.5	0.00	327824.3
Jul	7	15700	608.3	9350	9692.48	49874.41	0.53	0.00	413050
Aug	8	15700	608.3	9350	9889.28	50699.3	0.55	0.00	499297.5
Sep	9	15700	608.3	9350	9348.07	41792.97	0.43	0.01	576097.3
Oct	10	15700	608.3	9350	9889.28	21716.51	0.2	0.01	633361.6
Nov	11	15700	608.3	9350	9544.88	1731.30	0.00	0.00	670296.3
Dec	12	15700	608.3	9350	9692.48	4634.4	0.00	0.01	**710281.4**
TOTAL		188400	7300	112200	115473.32	286905.25	2.73	0.09	

Table X-3: Monthly and total electric consumption



Graph X-6: Monthly and total electric consumption

As said in previous chapters, to satisfy the new Italian regulation, the plants must use at least 50% of renewable energy to satisfy internal comfort. To calculate the percentage of renewable energy used the code provide the Table II-1, in which can be found the portion of renewable energy based on the energy vector type. In the case analyzed in this chapter, the two energy vectors used are the electricity from the net and the fuel used by the boiler. The electricity took from the national network, has a ratio of 0,47/2,42 of renewable energy used, instead the electricity produced by the PV has a 100% ratio of renewable energy used.

Moreover, as said in the Chapter 2.2.2, part of the primary energy of the heat pump can be considered as renewable using the equations Equation II-2 and Equation II-3 (Table X-4). This because the heat pump uses the environment air to work and it can be considered as a renewable energy vector by the standard.

Epdc (kWh/year)	197192
Ep,pdc (kWh/year)	108662.1
SPF (-)	1.8
ERES (kWh/year)	88529.9

Table X-4: Renewable energy from heat pump

As said before the CHP uses gas to produce electrical and thermal energy but there's also the possibility to use biogas to make it work. It is a huge advantage because the 60% of it can be considered renewable. In the following tables the calculations with both the energy vector have been made to understand better the differences in using these two different fuels.

Type	Type of vector	Quantity (kWh)
Fridges	Electricity national network	188400
Equipment	Electricity national network	7300
Lighting	Electricity national network	112200
FAN	Electricity national network	115473.32
Chiller	Electricity national network	242003.55
Heat pump	Electricity national network	44901.7
Chiller pump	Electricity national network	2.73
Boiler pump	Electricity national network	0.09
PV panel	Energy Produced	339418.76

Table X-5: Total energy summary

Cogegnerator gas consumption	Cogegnerator el production	Cogegnerator th production
2224973	705776.00	1169050.00

Table X-6: Total CHP production and consumption

RENEWABLE ENERGY CALCUALTION (BIOGAS)		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	4505.39	2181	8722	61.34
Total amount from PV (kWh/year)	0.00	0.00	0	
Total amount from HP (kWh/year)	44901.70	88529.0	0	
Total amount of gas (kWh/year)	2224973	1334983.8	889989.2	

Table X-7: Renewable energy summary for biogas

RENEWABLE ENERGY CALCUALTION (GAS)		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	4505.39	2181	8722	3.72
Total amount from PV (kWh/year)	0.00	0.00	0	
Total amount from HP (kWh/year)	44901.70	88529.0	0	
Total amount of gas (kWh/year)	2224973	0	2336221.65	

Table X-8: Renewable energy summary for gas

Seeing Table X-7 and Table X-8 is possible to see clearly the difference between using biogas or not. In the first case a percentage of 61.34% has been reach that is pliantly higher than the minimum value given by the standard. The second case, instead, is very negative; this because a large amount of gas by the network is used to make the CHP works but this type of energy vector has no renewable percentage and is the worst case found until now.

XI. DEC + CHP

In the previous solution, a CHP has been analysed to understand if it was enough to cover the energy needs of the building reaching the 50% of renewable energy used. In this last system solution the AHU is substituted by a desiccant air handling unit. The DEC should reduce the energy needs during the summer period, because it works exploiting the latent energy of the exhaust air deriving from the building.

The plant model (Figure XI-1) is composed by desiccant air-handling unit system and as generation subsystem are used a cogeneration system, that produce electricity and hot water, a chiller, that produce cooled water to let the back-up cooling coil placed in the DEC, and a heat-pump that work just when the CHP doesn't support the thermal energy needs. All the in-site generation systems are connected to the national network.

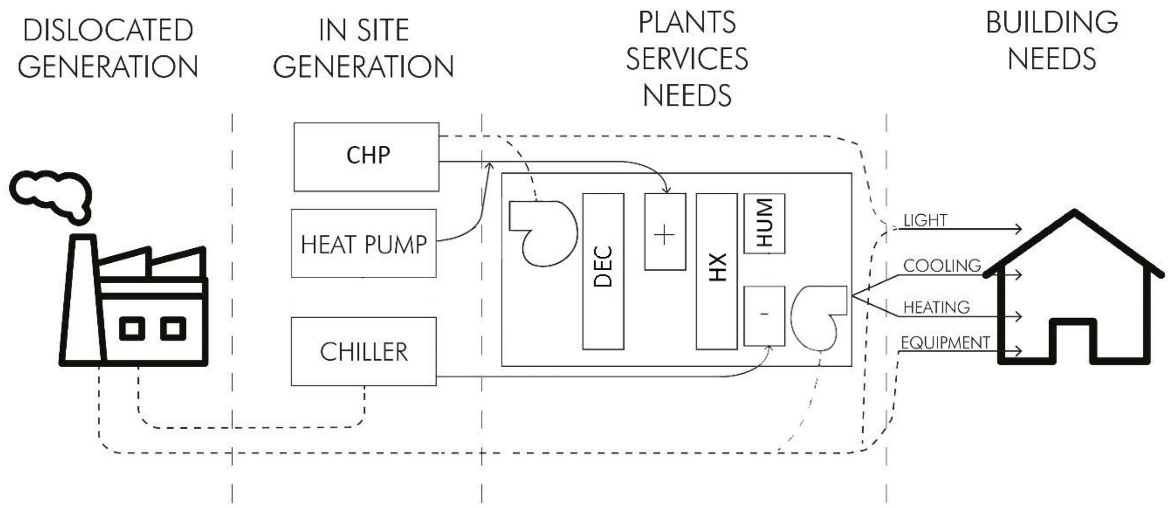


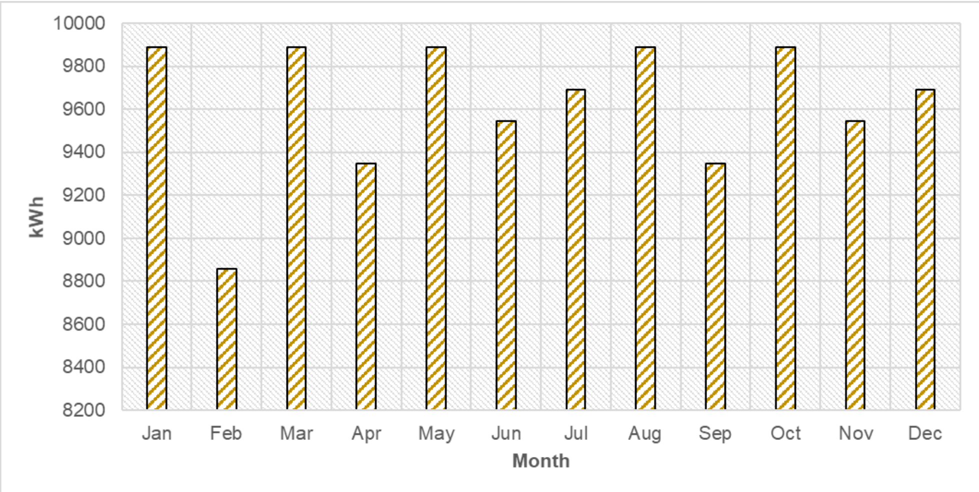
Figure XI-1: DEC + CHP plant scheme

The differences, in the trnsys model, between this case and the baseline case are the presence of a heat pump to produced heated water, instead of the boiler, and the differ type of AHU that should be much more performant in terms of energy needs during the summer period. The heat pump and CHP models are the same of the previous cases because the electric energy needs of the building are not so much affected by the AHU type, so the electric power production requested to the CHP remain almost the same. As in the other systems proposed, the building needs are independently from the plants types, can be considered constant in all the simulations and are showed in Graph VI-4. Following the results of the trnsys dynamic simulation for the remaining parts of the plants.

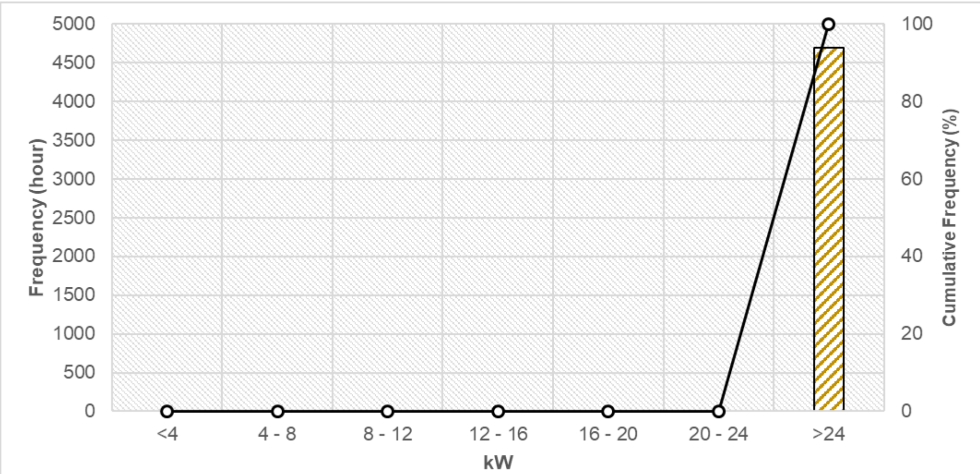
11.1 Plants services needs

Among the plants services needs can be found three different energy inputs request by the DEC to produce the inlet air:

- Electric energy requested to the fan: In the DEC AHU is possible to find two fans, one to let the air flow through the environment, and one to suck the exhaust air from the internal environment and push it into the humidifier that start the process. The electric energy needed by the fans has been found out in trnsys, following are showed the monthly electric energy requested by these systems and the frequency at which the energy is requested.



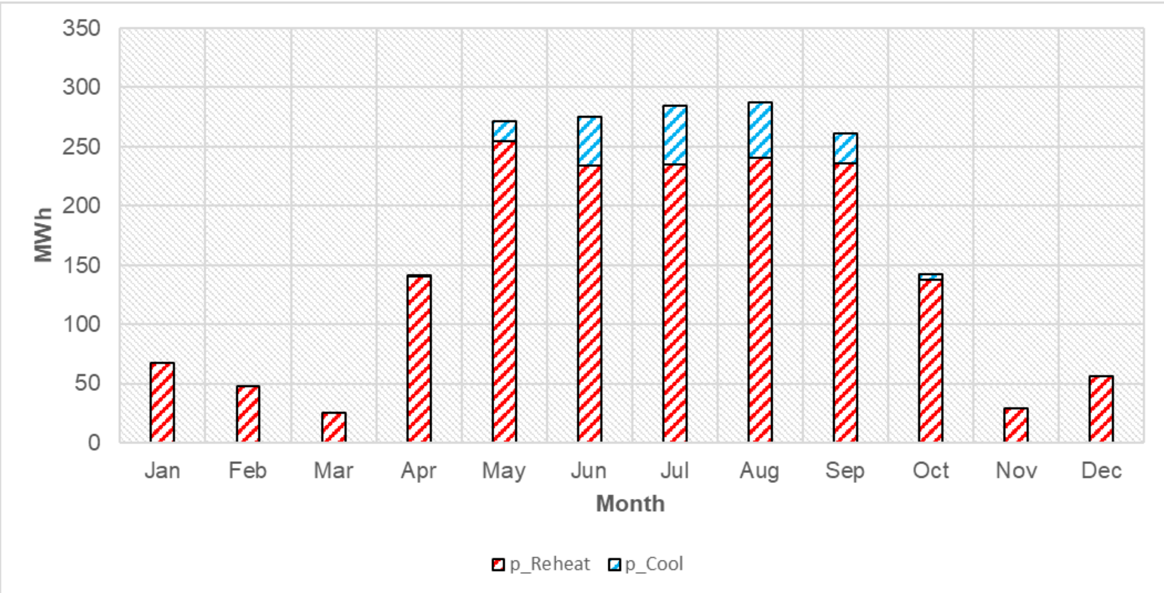
Graph XI-1: Fan power consumption



Graph XI-2: Fan power frequency

Also in this case, as shown in the graphs above, the fan power consumption is constant during the year, as expected and is equal to the one seen in the baseline (Graph VIII-1). Also the frequency graph is almost constant, this is due to the constant air flow rate that flow through the DEC.

- The second thing analysed was the energy need requested by the DEC to the entire process that lead the fresh air flow rate, from the external environment condition to the inlet condition. What could be expected, respect the other cases, is that the cooling energy requested during the cooling season will be lower, this because the DEC exploits the latent energy contained in the exhaust air to cool dehumidify the air stream, and then thanks to a heat exchanger recovers sensible energy. Before are showed the results.



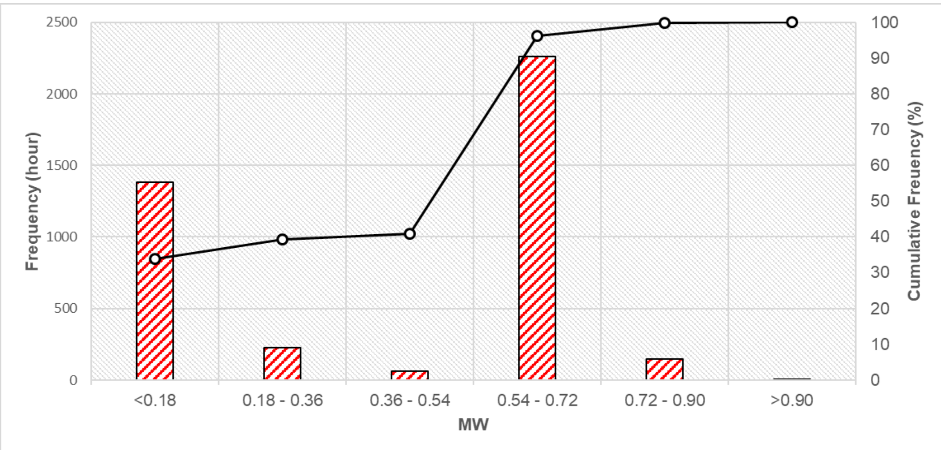
Graph XI-3: Total post-heating and cooling energy need

As was expected, the cooling energy demands are much lower than the other case, but the heating energy needs are increase. The growth of the heating energy requested is due to the heating coil that should heat the exhaust air stream till 60 degrees to let it subtract humidity by the external air stream.

Month		p_Reheat	p_Cool
Jan	1	67.86	0.00
Feb	2	47.34	0.00
Mar	3	25.41	0.00
Apr	4	140.46	0.63
May	5	254.46	17.00
Jun	6	234.26	40.92
Jul	7	235.18	49.31
Aug	8	240.24	46.99
Sep	9	235.47	25.97
Oct	10	137.92	4.22
Nov	11	29.31	0.00
Dec	12	56.20	0.00
TOTAL		**1704.11**	**185.04**

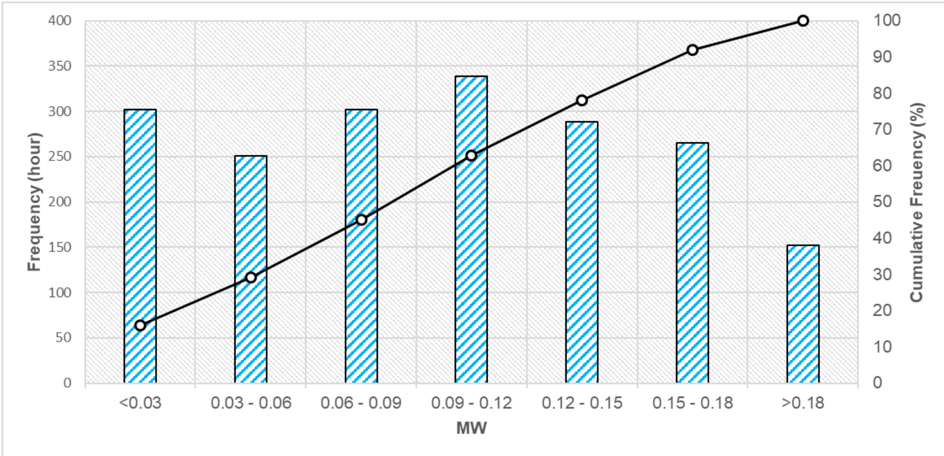
Table XI-1: Post heating and cooling battery energy needs

- Hot water requested by the post-heating coil: in the DEC system there is only the heating coil placed before the desiccant wheel that heat the exhaust air till 60 degrees. The hot water frequency power by the system was analysed using trnsys and the result is showed below in Graph XI-4.



Graph XI-4: Post heating coil frequency power

- Cold water requested by the cooling coil: the cooling coil is the only part of the system that requires chilled water to work, so the dimension of the electric chiller pump is directly affected by the energy needs of the cooling coil. In this case the cooling coil work less hour and with less power, because works just if the desiccant wheel and the heat exchanger are not enough to reach the inlet condition. The results of the simulation with trnsys are showed in Graph XI-5. Studying the frequency and finding its peak is possible to design the chiller that will be used in the system.



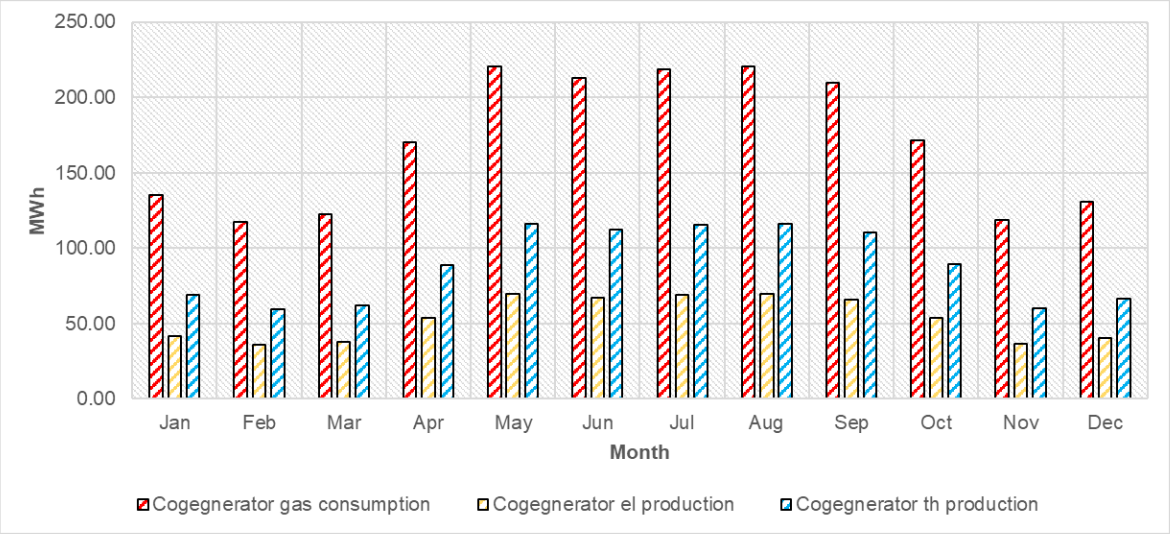
Graph XI-5: Cooling coil frequency power

11.2 In site generation

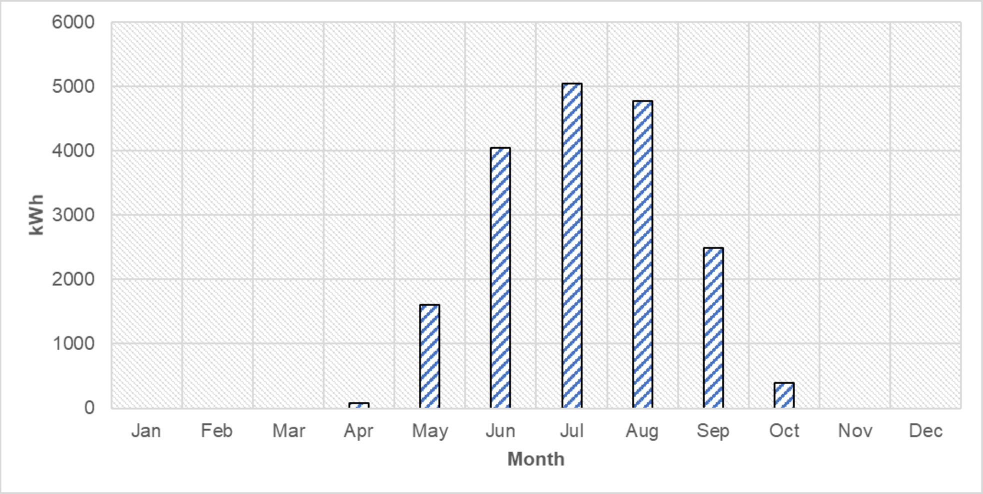
In the case under analysis, as in site generation systems are utilised, as in the last case, a CHP to produce electric and thermal energy, a chiller to produce cooled water and a heat pump (air-water heat pump) to produce hot water. The chiller and the heat pump work with the same energy vector, electricity.

The CHP types is the same of the previous case, because the electric peak power is almost the same of the previous one. Following is shown the energy produced by the CHP and the gas consumption.

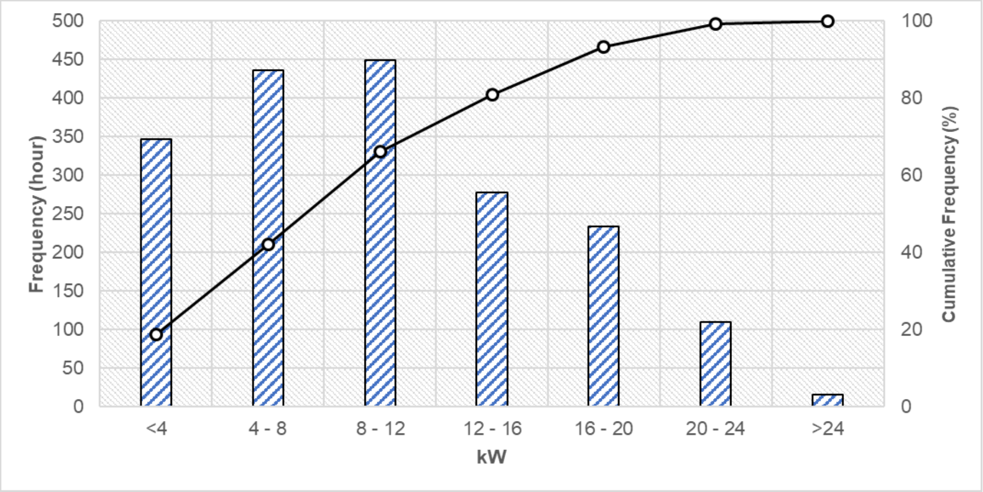
The Graph XI-7 shows the energy that the chiller requires all year long while, the Graph XI-8, shows the frequency of the power at which the chiller works. Using the frequency graph is possible to dimension the chiller, that should be a peak power of 25 kW. The peak power in this case is much lower than the other cases because the chiller work less hour and with less power due to the use of DEC.



Graph XI-6: CHP yearly production and consumption

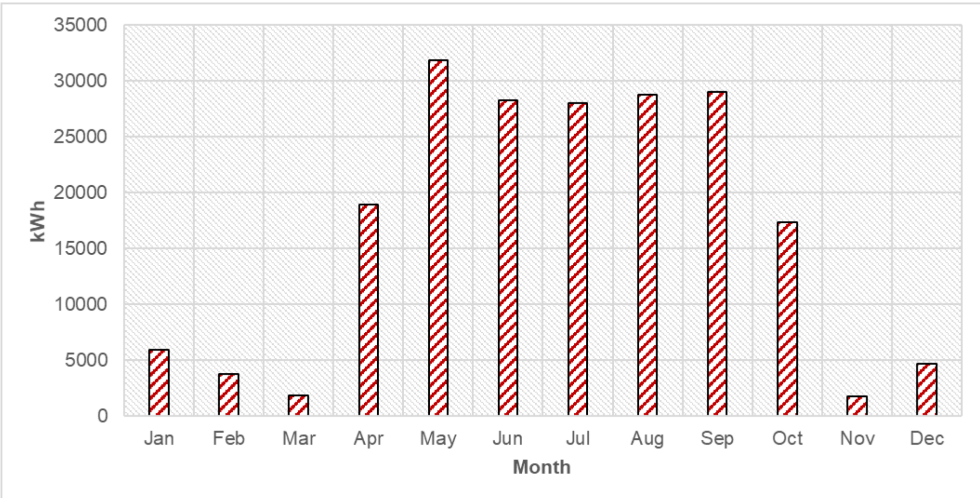


Graph XI-7: Chiller energy need

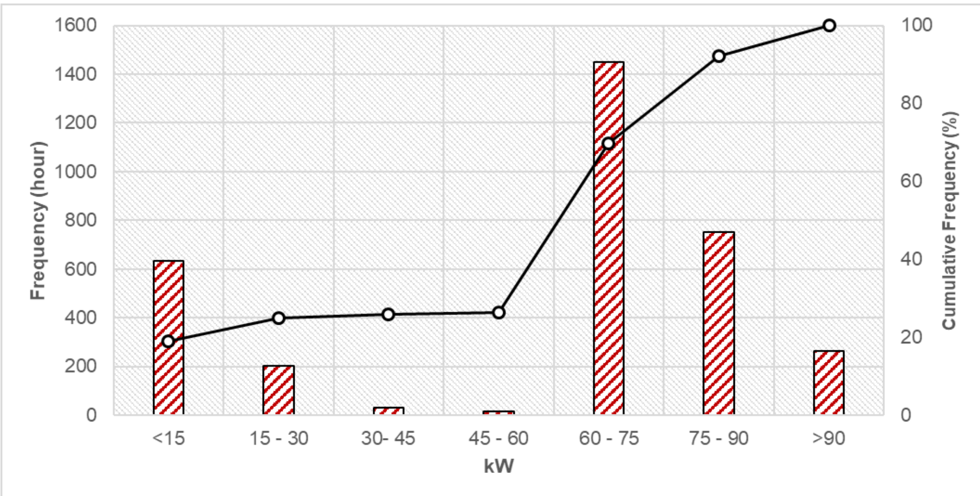


Graph XI-8: Chiller power frequency

For the heat pump has been computed the energy that the machine must produce to satisfy the hot water needs. In the case under analysis the heat pump works just if the CHP is not enough to cover all the energy needs. Using trnsys a dynamic simulation has been done and the heat pump power consumption has been carried out. The Graph XI-9 shows the energy that the heat pump requires all year long while, the Graph XI-10, shows the frequency of the power at which the heat pump works. From the graph below is possible to understand that the power requested to the heat pump is below 100 kW for almost all the year while the peak power is about 210 kW.



Graph XI-9: Heat pump energy need



Graph XI-10: Heat pump power frequency

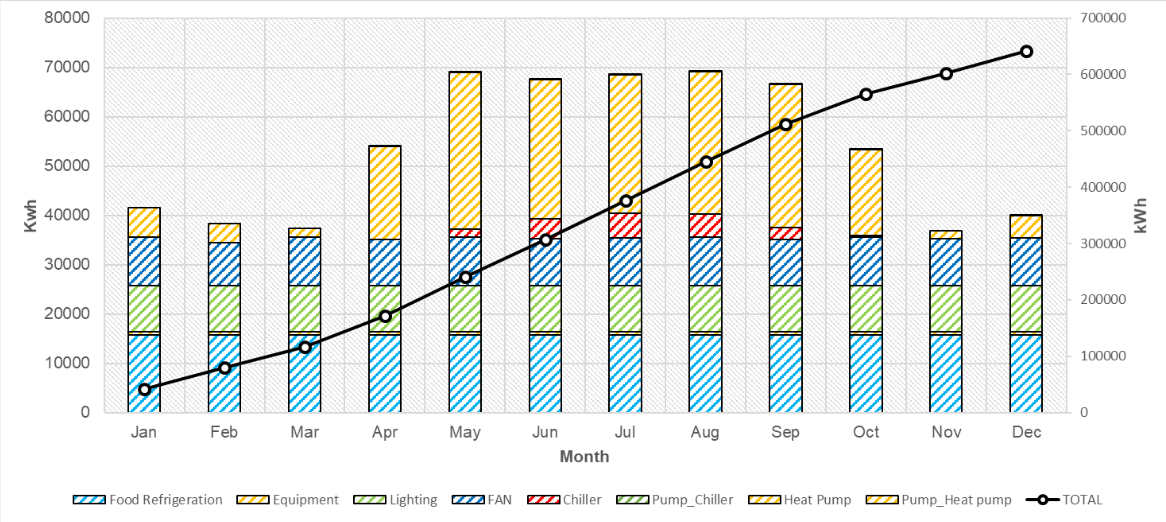
11.3 Dislocated generation

To understand if the system analysed in this chapter could be a solution, the energy needs requested by a dislocated source must be computed. The energy requested from the system to the national network is of two types: the energy used by the CHP and the electric energy (if the electric energy produced by the CHP is not enough).

Following are shown the electric energy needs in all the phases of the plants system.

Month		Food refrigeration	Equipment	Light	Fan	Chiller + heat pump	Chiller pump	HP pump	TOTAL (kWh)
Jan	1	15700	608.3	9350	9899.28	5919.88	0.00	0.01	41467.5
Feb	2	15700	608.3	9350	8856.07	3767.2	0.00	0.01	79749.2
Mar	3	15700	608.3	9350	9899.28	1790.9	0.00	0.00	117087.7
Apr	4	15700	608.3	9350	9348.07	18973.17	0.00	0.12	171067.4
May	5	15700	608.3	9350	9889.28	33431.58	0.02	0.19	240046.8
Jun	6	15700	608.3	9350	9544.88	32262.91	0.07	0.16	307513.1
Jul	7	15700	608.3	9350	9692.48	33044.34	0.09	0.15	375908.5
Aug	8	15700	608.3	9350	9889.28	33493.91	0.09	0.16	444950.3
Sep	9	15700	608.3	9350	9348.07	31482.98	0.04	0.17	511439.9
Oct	10	15700	608.3	9350	9889.28	17695.09	0.0	0.10	564682.7
Nov	11	15700	608.3	9350	9544.88	1731.52	0.00	0.00	601617.4
Dec	12	15700	608.3	9350	9692.48	4634.09	0.00	0.01	
TOTAL		188400	7300	112200	115473.32	218227.63	0.32	1.09	**641605.3**

Table XI-2: Monthly and total electric consumption



Graph XI-11:Monthly and total electric consumption

As said in previous chapters, to satisfy the new Italian regulation, the plants must use at least 50% of renewable energy to satisfy internal comfort. To calculate the percentage of renewable energy used the code provide the Table II-1, in which can be found the portion of renewable energy based on the energy vector type. In the case analyzed in this chapter, the two energy vectors used are the electricity from the net and the fuel used by the boiler. The electricity took from the national network, has a ratio of 0,47/2,42 of renewable energy used, instead the electricity produced by the PV has a 100% ratio of renewable energy used.

Moreover, as said in the Chapter 2.2.2, part of the primary energy of the heat pump can be considered as renewable using the equations Equation II-2 and Equation II-3 (Table IX-3). This because the heat pump uses the environment air to work and it can be considered as a renewable energy vector by the standard.

Epdc	966218.0
Ep,pdc	483506.5
SPF	2.0
ERES	482711.6

Table XI-3:Renewable energy from heat pump

Summarizing the results, is possible to see that using a natural gas is not possible to reach the percentage of renewable energy used by the system. Instead using biogas is possible to reach the 67,56%. The percentage increase respect to other systems because the heat pump work much more respect to the chiller because during the summer period the cooling energy requested by the coil is reduced by the use of DEC technology.

Type	Type of vector	Quantity (kWh)
Fridges	Electricity national network	188400
Equipment	Electricity national network	7300
Lighting	Electricity national network	112200
FAN	Electricity national network	115473.32
Chiller	Electricity national network	18431.58
Heat pump	Electricity national network	199796.06
Chiller pump	Electricity national network	0.32
Heat pump pump	Electricity national network	1.09
PV panel	Energy Produced	339418.76

Table XI-4: Total energy summary

RENEWABLE ENERGY CALCUALTION		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	1468.20	711	2842	67.56
Total amount from PV (kWh/year)	0.00	0.00	0	
Total amount from HP (kWh/year)	199796.06	482711.6	0	
Total amount of gas (kWh/year)	2048062.169	1228837.301	819224.8675	

Table XI-5: Renewable energy summary for biogas

RENEWABLE ENERGY CALCUALTION		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	1468.20	711	2842	18.33
Total amount from PV (kWh/year)	0.00	0.00	0	
Total amount from HP (kWh/year)	199796.06	482711.6	0	
Total amount of gas (kWh/year)	2048062.1	0	2150465.2	

Table XI-6: Renewable energy summary for gas

XII. DEC + SOLAR PANEL AND PV

Following the final considerations of the previous case study is possible to understand that, using an air handling unit with a desiccant wheel, the energy requested from the heating coil is the consumption driven factor. So, a solution to increase the efficiency of the system and reduce the primary energy consumption, could be achieve the energy needs of the heating coil using renewable strategy. In this chapter will be analysed the same plant system of the previous case study, but instead of the CHP to produce electricity and heat will be used coupled solar collector panel and photovoltaic panels.

The plant model, showed in Figure XII-1 is composed by desiccant air-handling unit system and as generation subsystem are used solar collector panels and photovoltaic panels that produce energy for the chiller and also the electric back up heat pump (the heat pump works just if the energy produced by the solar collector panel is not enough to cover the energy needs). All the in-site generation systems are connected to the national network, to cover the part of energy not produced by the system installed in site.

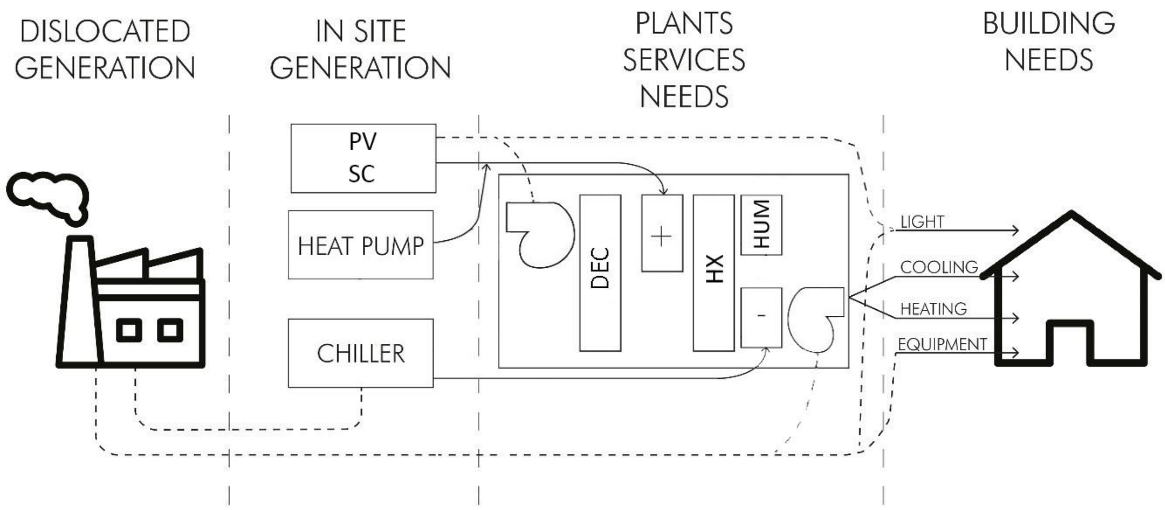


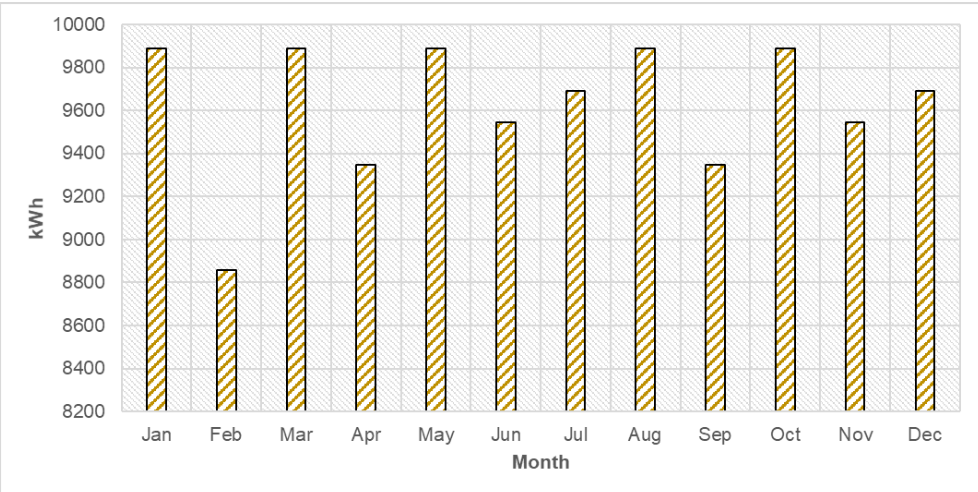
Figure XII-1: DEC + PV + SC plant scheme

The differences, in the trnsys model, between this case and the previous one is just in the energy production subsystem. The solar collector model selected for the simulation is a flat collector connected to a water storage. The water storage should be able to provide water at 65 degrees to the heating coils. Due to this, inside the boiler can be found another heat exchanger connected to the heat pump in order to cover the loads unmet by the solar collector panels. The water flux inside the solar panel and the coils are guarantee by two pumps. Following the results of the trnsys dynamic simulation for the remaining parts of the plants.

12.1 Plants services needs

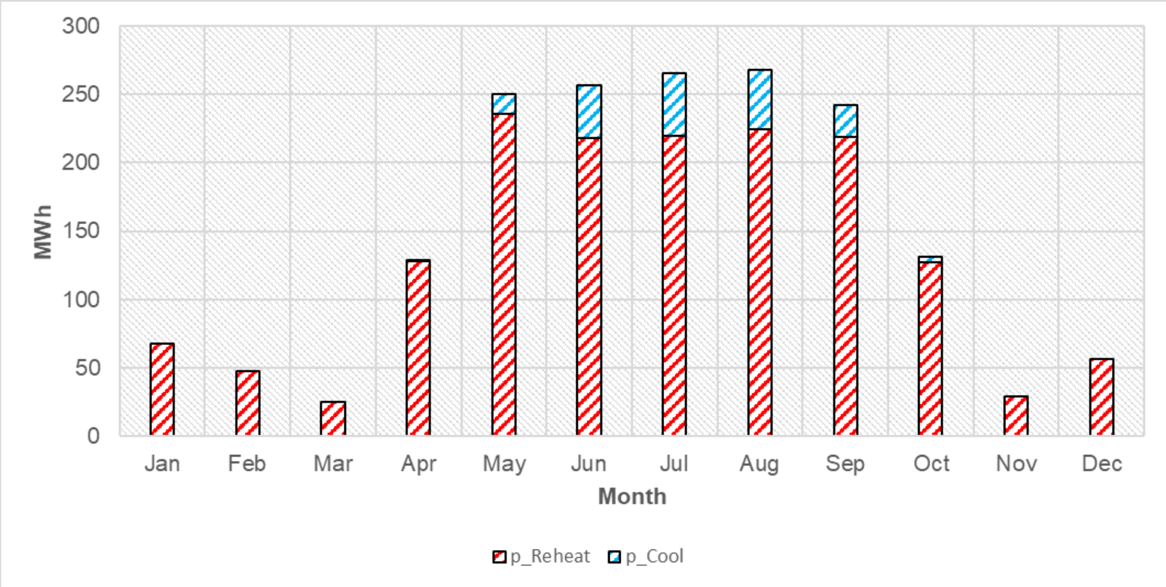
As for the previous cases, a list of energy inputs required to let the parts of the plant work is reported:

- Electric energy requested to the fans: The electric energy consumption of the fans, is the sum of the power absorbed by the two different fans present in the DEC AHU, one that suck the air out form the ambient, and one that let the air flow through the environment. In this case the energy consumption of the fans is almost the same of the previous case, because the main parameter that influence the power consumption is the flow rate, that is the same in the two different simulations.



Graph XII-1: Fan power consumption

- DEC energy needs request: is the energy request to the entire process that lead the fresh air flow rate, from the external environment condition to the inlet condition. What could be expected, respect the other case in which is used a DEC AHU, is that the cooling energy requested during the cooling season is slightly lower, this because change the water conditions that flows through the heating coil. These differences are generated by the production subsystem. In this case the production subsystem is composed by a tank heated by solar collector panels and a heat pump that has different power respect to the system analysed before composed by the CHP and the heat pump.



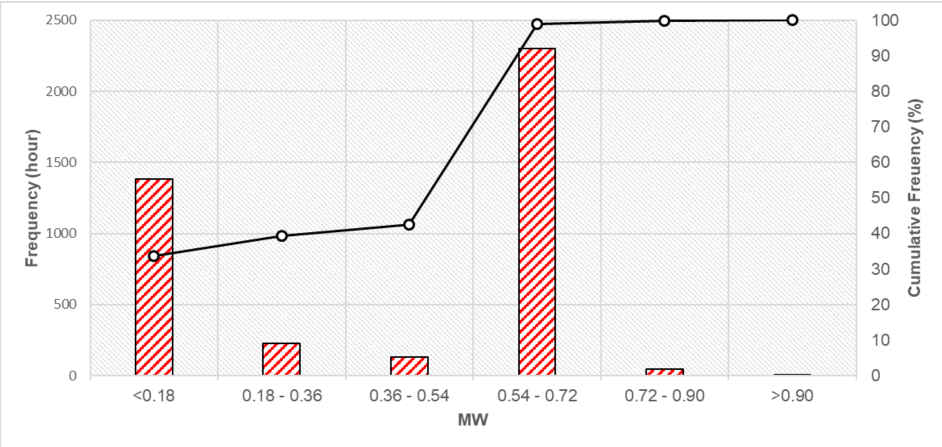
Graph XII-2: Total post-heating and cooling coil energy need

Month		p_Reheat	p_Cool
Jan	1	67.98	0.00
Feb	2	47.42	0.00
Mar	3	25.46	0.00
Apr	4	128.12	0.47
May	5	235.43	15.03
Jun	6	218.26	37.96
Jul	7	219.54	46.15
Aug	8	224.22	43.85
Sep	9	218.58	23.62
Oct	10	127.58	3.32
Nov	11	29.33	0.00
Dec	12	56.32	0.00
TOTAL		**1598.25**	**170.39**

Table XII-1: Post-heating and cooling battery energy needs

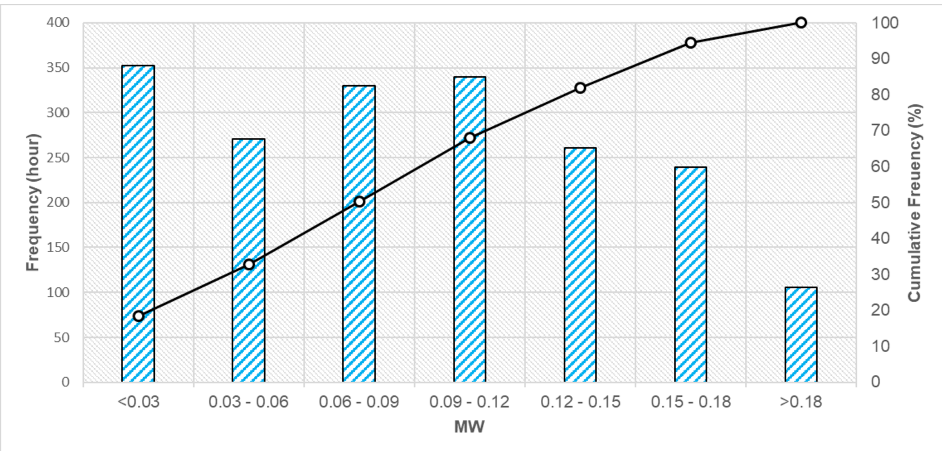
As a DEC AHU is used, during the summer period the energy consumption of the heating coil is much higher than the consumption of the cooling coil, because the cooling coil works just if the system is not able to take the air to the inlet condition, instead the heating works all year long.

From the graph Graph XII-3, that represents the frequency of the reheat coil energy requested, is clearly visible that there is a gap around 0.54. This gap is due to the season change, because when the DEC is operating, the energy request by the heating coil is much higher than during the winter period.



Graph XII-3: Post-heating coil frequency power

Thanks to the frequency graph of the cooling coil energy request is possible to dimension the chiller, because is the only one part of the system that works with cooled water. As can be appreciate from the Graph XII-4 the frequency of the cooling coil power is almost constant, so the dimension of the cooling coil power should be near the maximum.

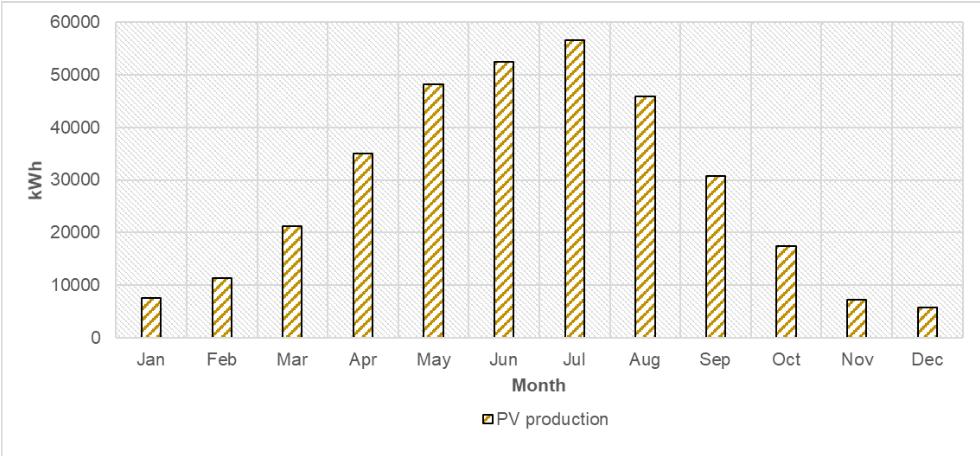


Graph XII-4: Cooling coil frequency power

12.2 In site generation

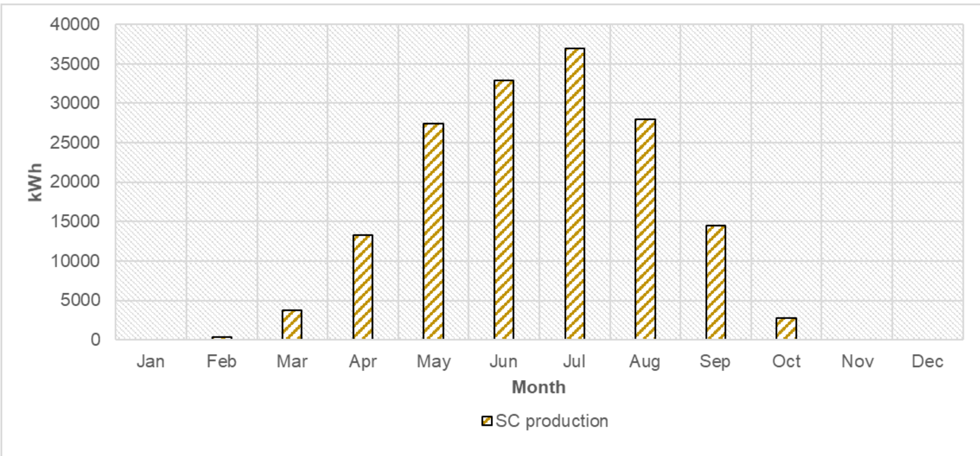
Also in the case of in-site generation systems, a list of the different energy vector produced, in the environment under analysis, can be done:

- Electric energy produced by photovoltaic panels: in the Graph XII-5 is possible to see the electric energy production, in the different months of the years, by the solar panels.



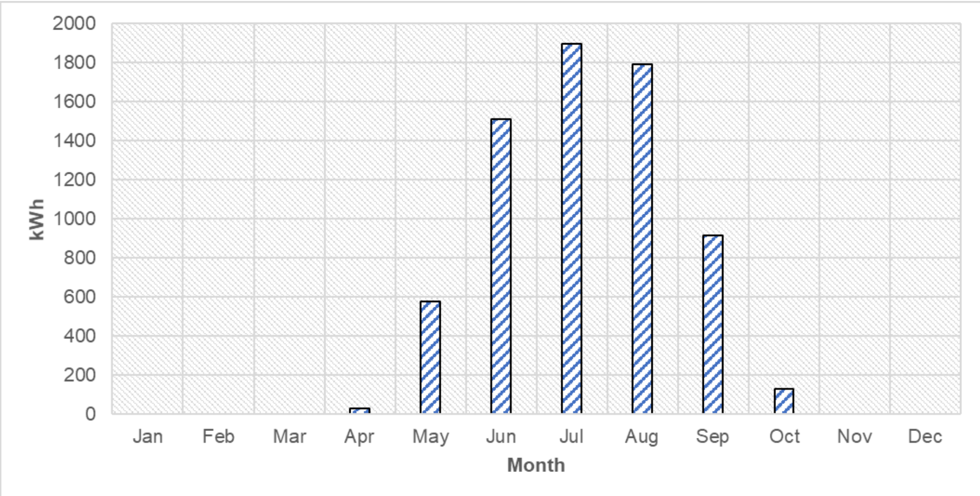
Graph XII-5: Photovoltaic electricity produced

- Solar collector energy production: in this plant system, 500 m^2 of solar collector has been analyzed. In the Graph XII-6 is possible to see the energy production of these square meters of solar panels.

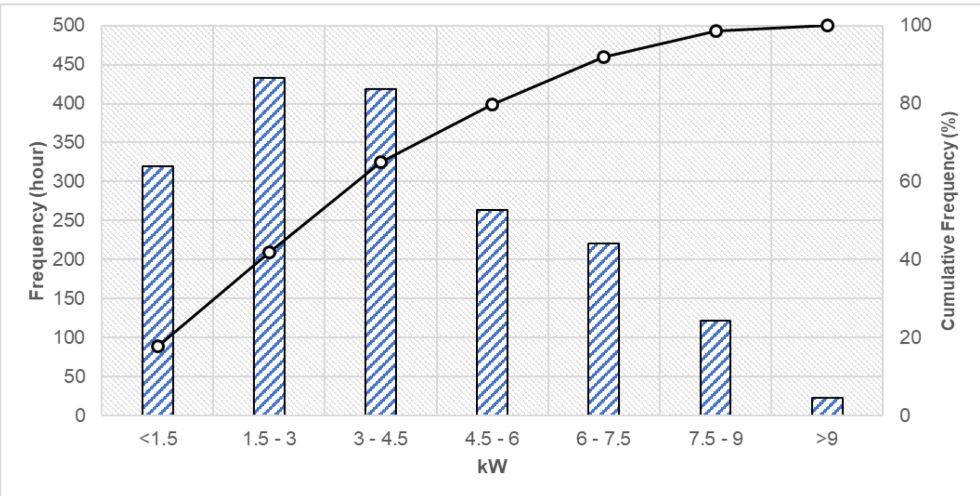


Graph XII-6: Solar collector energy produced

- Chiller power consumption: The Graph XII-7 shows the energy that the chiller requires all year long while, the Graph XII-8, shows the frequency of the power at which the chiller works. In this case study, the chiller works less than the other cases, this is due to the fact that thanks to the desiccant wheel and the heat exchanger, the DEC AHU is able to cover almost all the loads without the intervention of the beck up chiller. A 10 kW chiller will be enough for this type of plants.

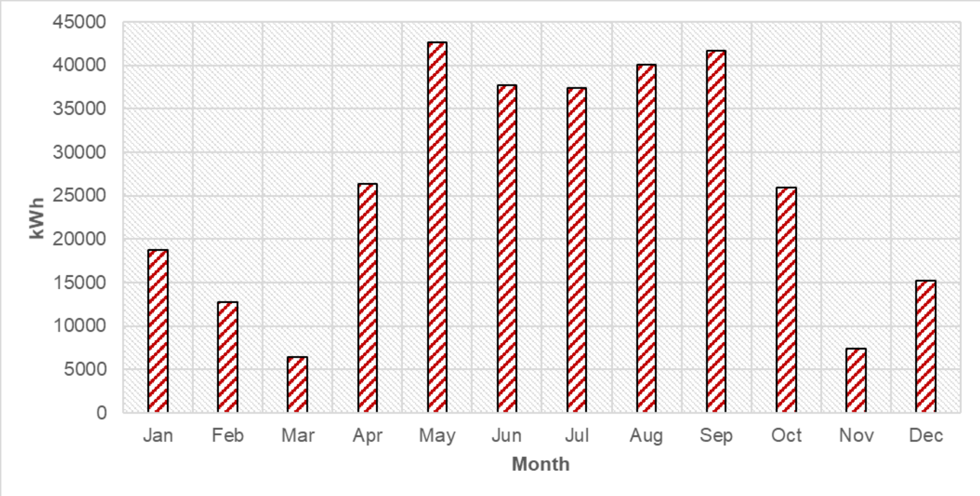


Graph XII-7: Chiller energy need

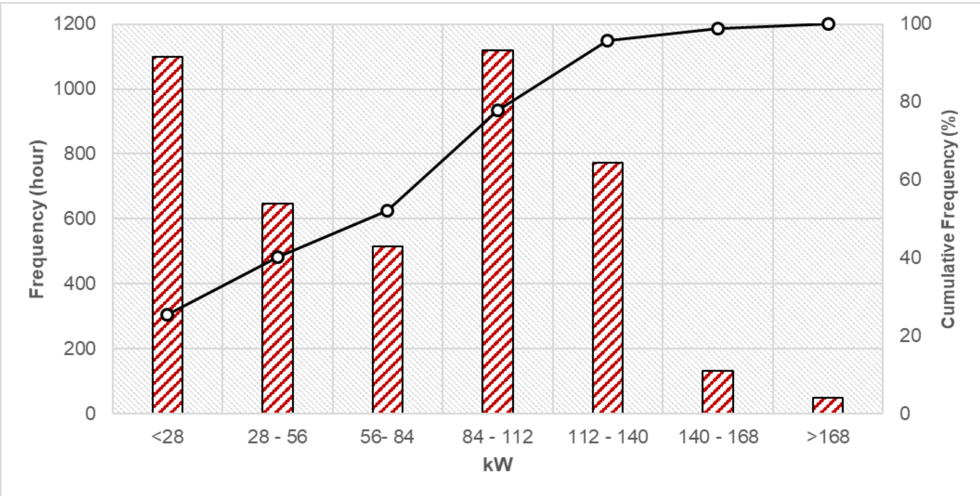


Graph XII-8: Chiller power frequency

- Heat pump power consumption: as can be appreciated from the Graph XII-9 is that the energy consumption of the heat pump is higher in this case respect to the case in which the CHP is used as generation subsystem (Graph XI-9). These increased loads dimension is due to the fact that the solar panels work well less hour respect to the CHP, that is able to produce energy independently by the atmospheric condition along all the year.



Graph XII-9: Heat pump energy need



Graph XII-10: Heat pump power frequency

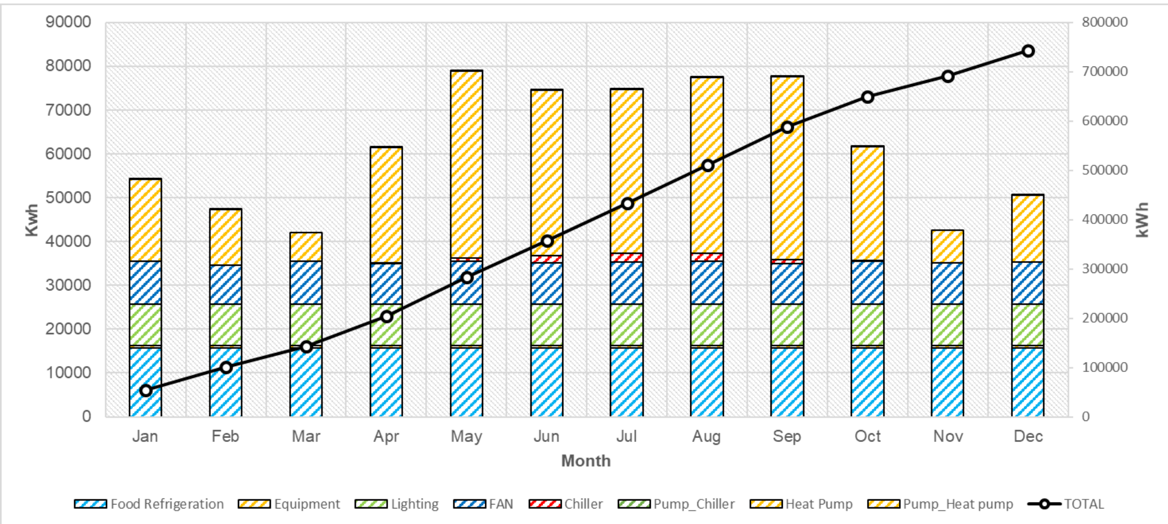
12.3 Dislocated generation

To make the calculations that leads to the amount of primary energy used, is important to calculate the amount of electric energy used in the system.

Following are shown the electric energy needs in all the phases of the plants system.

Month		Food refrigeration	Equipment	Light	Fan	Chiller + heat pump	Chiller pump	HP pump	TOTAL (kWh)
Jan	1	15700	608.3	9350	9899.28	18691.16	0.00	0.04	54238.8
Feb	2	15700	608.3	9350	8856.07	12722.85	0.00	0.03	101476.1
Mar	3	15700	608.3	9350	9899.28	6429.51	0.00	0.01	143453.2
Apr	4	15700	608.3	9350	9348.07	26340.64	0.00	0.17	204800.4
May	5	15700	608.3	9350	9889.28	43244.26	0.02	0.25	283592.5
Jun	6	15700	608.3	9350	9544.88	39250.71	0.07	0.21	358046.7
Jul	7	15700	608.3	9350	9692.48	39264.88	0.09	0.20	432662.7
Aug	8	15700	608.3	9350	9889.28	41854.01	0.08	0.22	510064.6
Sep	9	15700	608.3	9350	9348.07	42581.62	0.03	0.25	587652.9
Oct	10	15700	608.3	9350	9889.28	26019.24	0.00	0.16	649220
Nov	11	15700	608.3	9350	9544.88	7353.83	0.00	0.01	691777.0
Dec	12	15700	608.3	9350	9692.48	15206.35	0.00	0.03	**742334.2**
TOTAL		188400	7300	112200	115473.32	318959.07	0.29	1.58	

Table XII-2: Monthly and total electric consumption



Graph XII-11: Monthly and total electric consumption

The same calculations of the previous chapters are made also for this case study, starting from the heat pump.

Epdc	1438363.9
Ep,pdc	755335.2
SPF	1.9
ERES	683028.7

Table XII-3: Renewable energy from heat pump

At the end of the dynamic analysis, regarding this plants type, 57% of the energy used to reach the internal comfort is from renewable sources.

RENEWABLE ENERGY CALCUALTION		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	402915.50	195011	780044	63.84
Total amount from PV (kWh/year)	339418.76	339418.76	0	
Total amount from SC (kWh/year)	159884.05	159884.05	0	
Total amount from HP (kWh/year)	312122.00	683028.7	0	

Table XII-4: Renewable energy summary

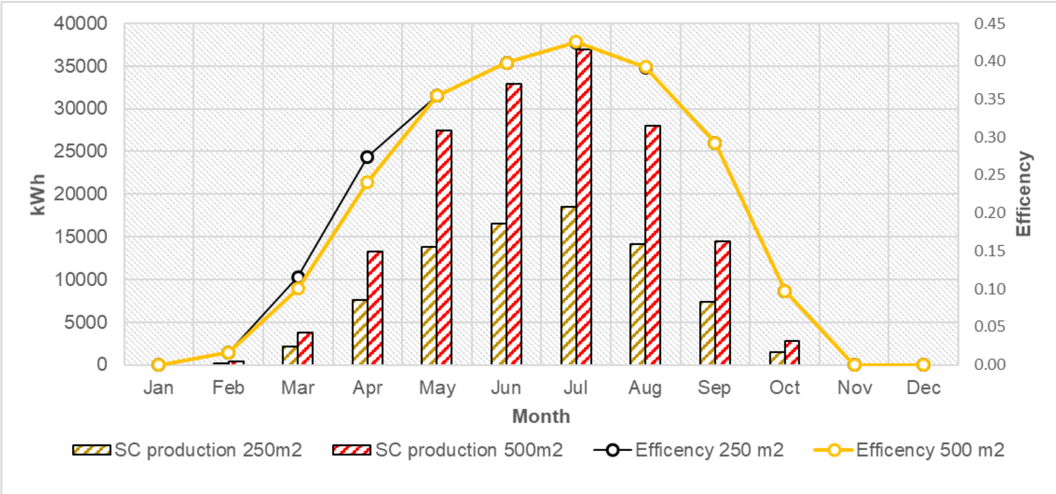
12.4 Further analysis

To find out if the quantity of photovoltaic panels and solar collector was the right one other analysis has been carried out. The first quantity that has been changed is the one of the solar collector passing from 500 m² to 250 m² and some consideration about the results has been made: looking at graph Graph XII-12 it's possible to notice that the configuration with the lower quantity of SC has an higher efficiency in some month of the year. Moreover, looking at the Table XII-5, the total renewable percentage is only 1.4% lower than the configuration with 500 m² of SC.

In the 250 m² configuration, obviously, the heat pump works more but it has been decided to go deeper in detail about this. Considering the cost of 250 m² of SC more (50000€) and the energy saving per year (2866€) the configuration with an higher quantity of solar collector has a returning period of 17 years. Considering that a solar collector has a nominal life of almost 20 year the best solution seems to be the one with 250 m² of solar panel matched with 1500 m² of PV panels.

Considering now the quantity of PV another analysis has been carried out. Have, in fact, been compared 2 different configurations, the one with 1500 m² of PV and 500 m² of SC and another one with 1000 m² of PV and 250 m² of SC.

This analysis has been made because, having with this configuration a renewable percentage of 63.84, it wanted to try to decrease the quantity of PV to see if the minimum renewable percentage was still reached.



Graph XII-12: Solar collector production and efficiency comparison

RENEWABLE ENERGY CALCUALTION		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	418832.73	202715	810860	62.41
Total amount from PV (kWh/year)	339418.76	339418.76	0	
Total amount from SC (kWh/year)	81825.04	81825.04	0	
Total amount from HP (kWh/year)	328039.27	722569.3	0	

Table XII-5: Renewable energy summary

Looking at the table below it's possible to notice that the minimum percentage it still reached so, also this one, is a good way to respect the standard even if the expense for the electricity will be higher. Looking, also in this case, at the economical aspect with the configuration with less PV and SC there is an initial save of almost 179000€ but the expense in electricity is much higher (23000€/year) so the returning period of the configuration with 1500 m^2 of PV and 500 m^2 of SC is 8 years.

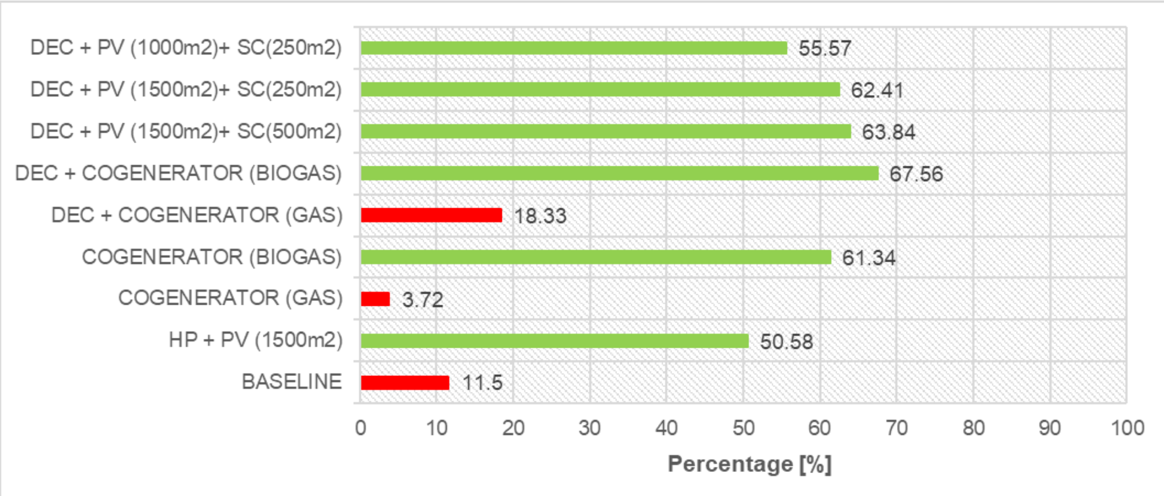
RENEWABLE ENERGY CALCUALTION		Primary Renewable	Primary Non Renewable	% Renewable energy
Total amount from network (kWh/year)	531972.32	257475	1029898	55.57
Total amount from PV (kWh/year)	226279.17	226279.17	0	
Total amount from SC (kWh/year)	159884.05	159884.05	0	
Total amount from HP (kWh/year)	328039.27	644510.3	0	

Table XII-6: Renewable energy summary

XIII. SYSTEMS COMPARISON

To conclude the analysis of the different plants modelled some considerations about the results obtained have to be done. All the configurations have brought to good results in terms of percentage of renewable energy used but some of them have inconvenient and are quite difficult to install in a urban environment.

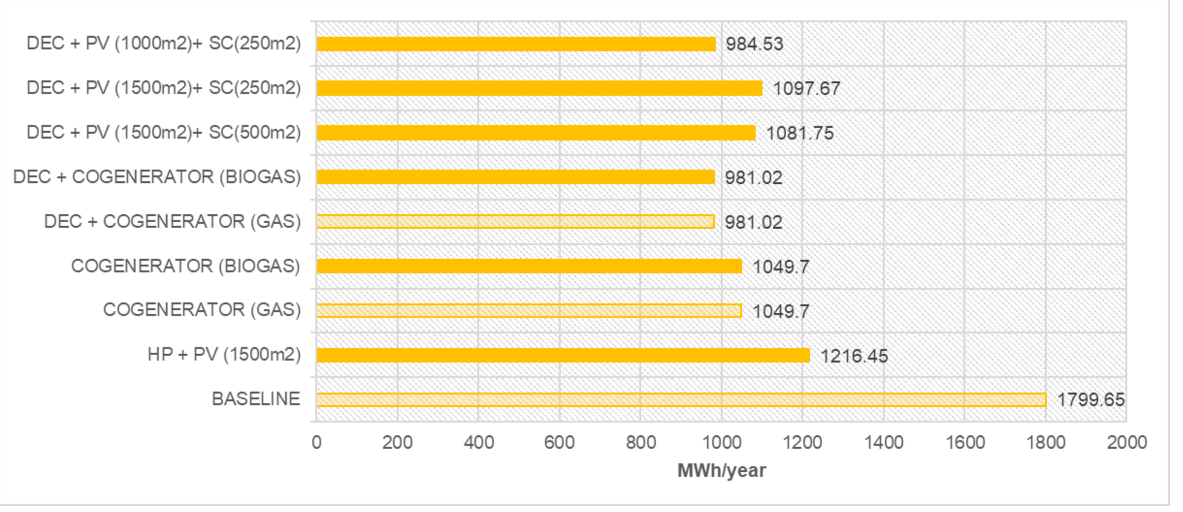
In the Graph XIII-1 a comparison among all the system analysed is shown. As clearly visible the baseline, that represent a plant system designed not taking into account the last standard (DGR 967/2015 [1]), doesn't respect the limit imposed. The other systems proposed respect the code threshold apart from the two plants in which is used a natural gas driven CHP.



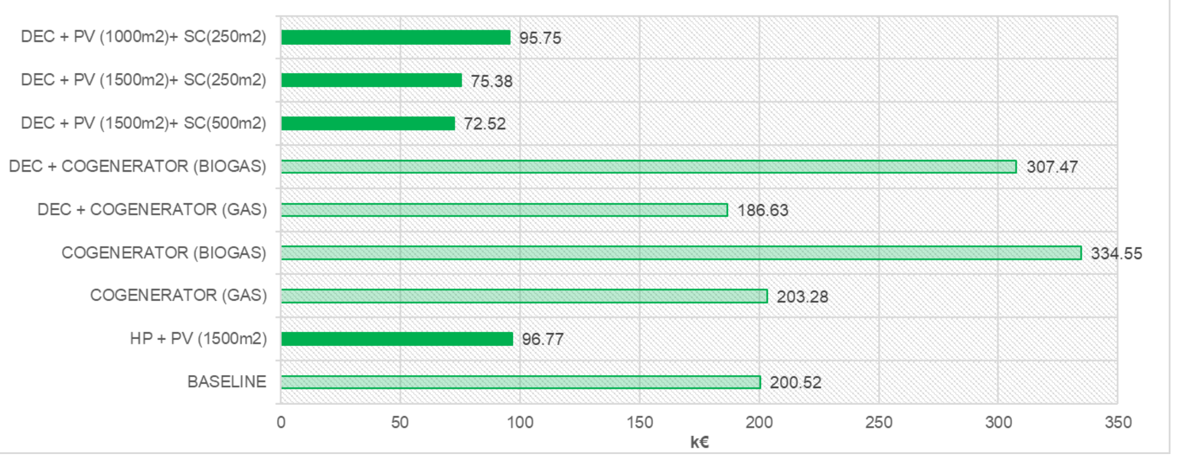
Graph XIII-1: Renewable primary energy percentage summary

The renewable primary energy percentage used is not the only parameter that should be considered designing a plant. To reduce the carbon dioxide emission, is important to reduce the energy requested by the system. The Graph XIII-2 shows the energy consumption for each plant. As the energy consumption of the nine different systems, that respect the renewable energy threshold, are almost equal, a further analysis on the total energy costs has been performed (Graph XIII-3).

Due to the high total cost and the difficult availability of the biogas fuel, the two systems proposed with the CHP has been excluded.



Graph XIII-2: Total energy summary for each system



Graph XIII-3: Whole energy cost summary

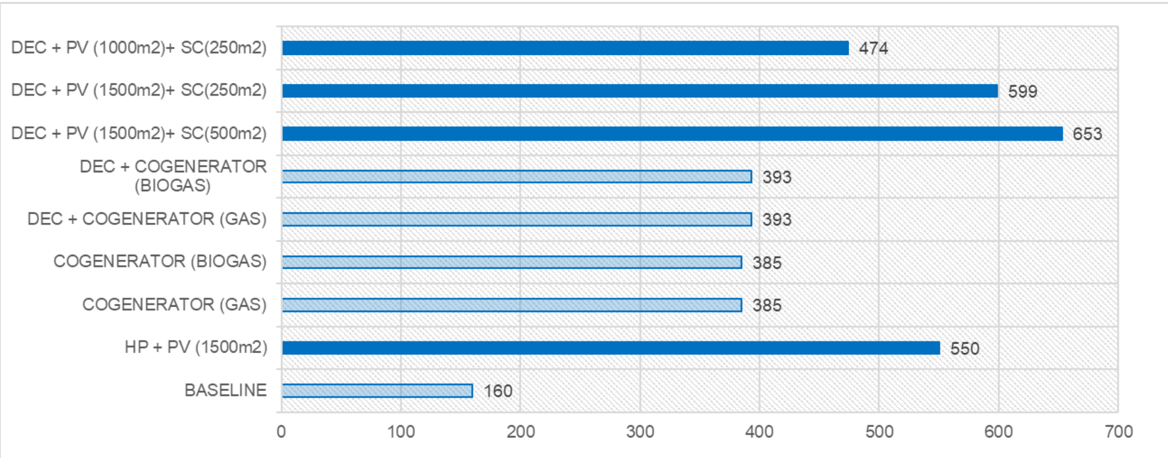
The cost analysis has been done using the prices from datasheet and "Prezziario di Milano per le opere pubbliche 2018" [39]. The prices for single component are shown in the table below (Table XIII-1).

The Graph XIII-4 shows the total cost of the machine that composed the different type of systems. Analyzing the four remaining plants (DEC +PV+SC and HP+PV).

These four remaining solutions are almost equivalent one to the others in terms of plant cost/energy cost and the choice between these systems depends only on the type of initial investment and the intentions of the building owner.

Type of Machine	Cost
Heat pump 120 kW	40.000 €/each
Heat pump 100 kW	35.000 €each
Heat pump 90 kW	30.000 €/each
Heat pump 60 kW	25.000 €/each
Chiller 150 kW	40.000 €/each
Chiller 25 kW	18.000 €/each
Chiller 10 kW	10.000 €/each
AHU	50.000 €/each
DEC AHU	60.000 €/each
CHP 200 kW	220.000 €/each
Boiler 500 kW	20.000 €/each
Photovoltaic panel ($2m^2$)	500 €/each
Solar collector panel ($2m^2$)	400 €/each

Table XIII-1: Machines costs



Graph XIII-4: Total plant cost summary

XIV. CONCLUSION

This thesis had as aim the definition, through dynamic simulations, of an air handling unit system for a new supermarket placed in Emilia Romagna region, in accordance with the DGR 967/2015. This standard introduced new energy requirements for public and private buildings to reduce carbon dioxide emission and face up climate changes.

The most important news introduced by the DGR 967/2015 is that the energy performance has to be calculated in both seasons, summer and winter. With the new legislation is mandatory also to look at the primary energy used for cooling, heating and domestic hot water that must derive at least for the 50% from renewable sources.

Four different plants configuration has been proposed and they are:

1) AHU combined with a chiller, a heat pump and a field of photovoltaic panels.
2) AHU combined with a chiller and a CHP (with a backup heat pump).
3) DEC AHU combined with a chiller and a CHP (with a backup heat pump).
4) DEC AHU combined with a chiller, a heat pump, a field of photovoltaic panels and solar thermal collectors.

From a brief weather analysis can be said that in Emilia Romagna the climate is characterized by hot and humid summer with cold and dry winter. A further solar radiation analysis has been performed showing that renewable energy sources like solar collector or photovoltaic panel can be very powerful during the summer period.

Subsequently, the dissertation passed to the building and plants model definition on the transient energy simulation environment (TRNSYS18), in order to perform dynamics simulations that allow to understand the differences in terms of energy needs and primary energy used in the four different case studies. The building model has been defined using the TRNSYS18 type56 and in accordance to the minimum requirements given by the Emilia Romagna code.

The first dynamic simulation performed was referred to the building energy needs. The most important point figured out by this analysis is that the energy needs related to the cooling period was higher than the heating needs, as can be expected in a supermarket, due the internal gains. Can be appreciated that in this type of building is important to reduce as much as possible the internal gains, things that could be possible using for example energy efficient light and equipment (like fridges and LED lighting).

Then, a simulation called “baseline” have been performed. This simulation has the aim to compare a plant compliant to the old regulation with the proposed plants layout. The baseline plant is composed by an all-air AHU coupled with a chiller and a boiler. From the calculation of the primary energy used, is showed that just the 11,5% derived by renewable primary energy as can be expected, because the only energy vector that influences the percentage is the electric energy taken from the national network that counts for 20% as renewable.

System 1) an all-air air handling unit has been used, trying to stay above the renewable energy threshold using a field of photovoltaic panels and a heat pump. Using a photovoltaic area of 1500 m^2 is possible to reach a percentage of 50,58% of renewable energy used. This percentage is reached also thanks to the amount of energy, that can be considered renewable, derived from the heat pump.

System 2) in this case study the field of PV has been changed with a CHP. The problem that is clearly visible from this analysis is that the cogenerator, if used with a fuel different from biogas, is totally non-renewable, in fact, for example, natural gas is used as energy vector, a percentage of 3,72% has been carried out.

System 3) As appreciated from the first two dynamic simulations, a big amount of renewable energy derives from the heat pump. Using a DEC AHU the energy requested by the heating coils increases, instead the energy requested by the cooling coil decreases. This increment in the heat pump can be appreciate from the percentage of renewable energy used, that rises till 18.33%, just changing the emission subsystem. This third simulation remain below the energy threshold because as said before the CHP use fuel to work, and can reach the threshold just if it is used with biogas (67,56%)

System 4) The last system proposed is the one that includes all the conclusion reached in the first three simulations. A DEC AHU is coupled with photovoltaic panels and solar collectors that give energy to the heat pump and the chiller (that become much smaller than the previous cases). Through the dynamic simulation a percentage of 63,84% has been carried out. This percentage is a consequence of the amount of energy produced by the solar collector and the photovoltaic panels, but also the energy produces from the heat pump, that is higher in this case respect to the last one, because the heat pump is the only energy source in the early morning hours and in the evening, when the sun is not enough to let the PV and SC work.

Further analysis on the amount of PV and SC that lead to reach the amount of 50% and reduce as much as possible the cost of the plants and the energy needs. From these analyses has been carried out that using an amount of 1000 m^2 of PV and 250 m^2 of SC can be saved 170000 euros on the initial investments spending more money for electricity during the year.

A final comparison has been performed among the possible systems analysed excluding the solutions that used the CHP technology that have been excluded because they are too much expensive and the biogas is not diffuse in all the national territory. Among the four different systems remained that respect the DGR 967/2015, the choice is of the building owner because depends just on the economic considerations.

XV. ABBREVIATION TABLE

ABBREVIATION	MEANING
Q	Energy
W	Power
AHU	Air Handling Unit
CHP	Cogenerator heat pump
HP	Heat pump
PV	Photovoltaic
SC	Solar Collector
DEC	Desiccant evaporative cooling
COP	Coefficient of performance
EER	Energy efficency ration

XVI. BIBLIOGRAPHY

Standard references

[1] *Regione Emilia Romagna, 2015-07-20 DGR 967 applicazione RM*

[2] *Regione Emilia Romagna, 2015-09-29 indicazioni fattori di conversione DAL 967/1275*

[3] *Regione Emilia Romagna, 2016-10-24 DGR 1751 modifiche applicazione RM*

[4] *Regione Emilia Romagna, 2008-03-04 DAL 156 procedure certificazione energetica*

[5] *Regione Emilia Romagna, 2014-10-13 DGR 1577 modifica DAL 156*

[6] *Decreto Legislativo 4 luglio 2014 aggiornato il 26 luglio 2016*

[7] *UNI 10339 – impianti aeraulici ai fini di benessere*

[8] *ASHRAE handbook*

[9] *DM 5 Settembre 2011, Regime di sostegno per la cogenerazione ad alto rendimento*

[10] *DL 90/2013 Recepimento direttiva 2010/31/UE*

[11] *D.Lgs 28 del 3/3/2011, Attuazione della direttiva 2009/28/CE*

Producers data sheets documentation

[12] *Carrier 39G Air handling Unit, July 2013*

[13] *Enerblu cogeneration REC2 200 G light*

[14] *Viessmann Vitocal 300-G/-W Pro, February 2017*

[15] *Mitsubishi Electric MLU Series PV-MLU255HC*

[16] *Solar collector Jodo 200*

[17] *3F Filippi Quadro LED, February 2018*

[18] *Costan eptarefrigeration Granvista Season, March 2016*

[19] *Costan eptarefigeration Granbering, March 2016*

Scientific papers and manuals

[20] *Andrzej Bugaj, "Energy and environmental evaluation of combined cooling, heating and power system", 2017*

[21] *Rocco Carfagna, Giuseppe Sorrentino, "Impianti di cogenerazione e trigenerazione, guida alla progettazione, realizzazione e gestione", Biblioteca Tecnica Hoepli, 2017*

[22] *Simone Ferrari, "Solare termico negli edifici", Edizioni Ambiente, Giugno 2008*

[23] *Thibaut Vitte, Jean Brau, Nadège Chatagnon, Monika Woloszyn, "Proposoal of new hybrid control strategy of a solar desiccant evaporative cooling air handling unit", July 2007*

[24] *Erica Zavaglio, "Modelling and simulation of desiccant wheels for the design and control of energy efficient air handling units", 2012*

[25] *G. Angrisani, C. Roselli, M. Sasso, "Distributed polygeneration: Desiccant based air handling units interacting with microcogeneration systems", 2013*

[26] *Hans Martin Henning, "Solar-assisted air conditioning in buildings, a handbook for planners", SpringerWien NewYork 2003*

[27] *TRNSYS 18, TRaNsient SYstem Simulation program, Volume 4 - Mathematical Reference*

[28] *TRNSYS 18, TRaNsient SYstem Simulation program, Volume 5 – Multizione building modelling with Type 56 and TRNBuild*

[29] *TRNSYS 18, TRaNsient System Simulation program, Volume 10 - Examples*

[30] *TESSLibs 17, Component libraries for the TRNSYS Simulation Environment, Volume 01 – Applications Library Mathematical References*

[31] *TESSLibs 17, Component libraries for the TRNSYS Simulation Environment, Volume 06 – HVAC Library Mathematical Reference*

[32] *TESSLibs 17, Component libraries for the TRNSYS Simulation Environment, Volume 07 – Hydronics Library Mathematical Reference*

[33] *TESSLibs 17, Component libraries for the TRNSYS Simulation Environment, Volume 11 – Storage Tank Library Mathematical Reference*

[34] *http://www.trnsys.com/*

[35] *https://www.sketchup.com/it*

[36] *https://energyplus.net/weather*

[37] *https://it.mathworks.com/products/matlab.html*

[38] Alessandro Ragazzoni, "Analisi della redditività degli impianti a biogas alla luce delle nuove tariffe incentivanti", Università di Bologna (Dipartimento di Scienze Agrarie), Marzo 2013

[39] Comune di Milano, "Listino prezzi per l'esecuzione di opere pubbliche e manutenzioni", 2018