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Influence of microclimate boundary conditions in net zero energy settlements on HVAC efficiency

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Abstract. Net zero energy buildings (NZEB) represent reality of new constructions in Europe for environmentally sustainable energy efficiency. The shift to net zero energy settlements represents a further opportunity to achieve extra-energy saving, thanks to utilities sharing, renewables optimization, and microclimate mitigation. This last aspect concerns the opportunity to improve settlements outdoor microclimate conditions in both hot and cold seasons, in a variety of climate conditions, with the purpose to improve occupants' wellbeing. At the same time, microclimate mitigation at inter-building scale may also involve relatively less severe boundary conditions able to reduce both cooling and heating demand of buildings and better working conditions for HVAC systems, e.g. heat pumps and air-to-air heat exchangers. This extra-energy saving, achievable with no extra costs, may represent an interesting opportunity to be taken into account in net zero energy settlements design and construction. This study analyzes this energy saving in a net zero energy settlement in Italy, built thanks to an on-going Horizon 2020 project. The influence of microclimate mitigation strategies is assessed in terms of energy saving benefits for the heat pump working conditions. Results demonstrate that this further benefit represents a non-negligible, environmentally sustainable, strategy for energy efficiency of NZEB in new inter-building scale developments.

1. Introduction

The Urban Heat Island phenomenon has a strong impact on building and HVAC system performances. In fact, the increased absorption of solar radiation, the reduced heat losses, and the anthropogenic heat result in a positive thermal balance of cities and, therefore, in higher temperatures which affect the energy demand and consumption for cooling [1]. Accordingly, climate change has negative impact on energy and peak electricity demand as described in [2] and affects the efficiency of the air conditioner considerably while increasing the building cooling needs [3]. Microclimate mitigation techniques represent acknowledged technologies to reduce the impact of this climate change related phenomena. The main strategies are the implementation of evaporative system (water-based), reflective materials, and urban greenery [4].

In this work, dynamic building energy simulation by means of EnergyPlus simulation engine is carried out to assess the cooling consumption reduction and the HVAC energy efficiency increase is summer associated to the implementation of microclimate mitigation technologies at settlement level. To this aim, weather files are generated starting from a previous work [5] in the framework of an on-going H2020 project and then modified with the evidence of other environmental mitigation studies [6]. Furthermore, a mathematical model of the direct expansion cooling system, based on performance curves which are function of air temperature at the evaporator and condenser side, is implemented to simulate the component physics.

Therefore, two microclimate scenarios are investigated (i) unmitigated and (ii) mitigated and the results in terms of variation of the energy consumption and the energy efficiency ratio (EER) for the direct expansion system are evaluated and compared.

2. Methods

### 2.1 Development of weather files mitigation

In a previous work described in [5], the implementation of microclimate mitigation strategies in a specific settlement, i.e. increase of the percentage of vegetation and of the solar reflectance capability of the built environment, is analysed by means of ENVI-met software. Therefore, a weather file is generated by considering the maximum effect of the combination of the two mitigation strategies starting from microclimate simulation outputs in terms of dry-bulb temperature, direct and diffuse solar radiation and wind speed for one day in summer and another in winter through a dedicated MATLAB tool, as detailed in [5]. The procedure applied for generating the weather file involves the sinusoidal and linear interpolation of the ratio between the optimized and reference parameters on daily and annual basis. Moreover, a weather file representing the reference unmitigated scenarios is developed by applying the same procedure.

In this work, in addition, the generated mitigated climate file is subsequently improved in Elements (BigLadder software) to consider the possible further reduction due to the implementation of evaporative mitigation technologies, by considering an average temperature decrease of 2 K as a representative average from the analysis carried out in [6].

2.2 Case study building and thermal-energy model

The building type analysed is a single-family detached house with a gross conditioned area of about 200 m^2, located in Italy in the municipality of Granarolo Dell'Emilia, near the city of Bologna.

The building shape is rectangular with sloped roof. According to the purpose of the work, the building model construction meets the requirements of the Italian regulations for NZEB buildings [7]. Since the definition of NZEB building also includes the HVAC system, an iterative procedure is carried out, once modelled the HVAC system, to meet the primary energy consumption requirements by starting from a reference building and selecting the thermal properties of the building envelope and HVAC system parameters. The materials chosen for the building envelope are masonry with high-density wood fibre insulation for the south-facing wall and medium-density wood fibre insulation for the other walls. Also, the ground floor and the roof are thermally insulated, the latter is also highly reflective to solar radiation thanks to the implementation of cool materials on the external layer. The transparent surfaces are triple-glazed windows with argon filling gas and a shading system with blind is inserted to ensure the necessary shading during the summer season. Figure 1 shows the building energy model by outdoor boundary conditions, construction type, surface type, and thermal zones.
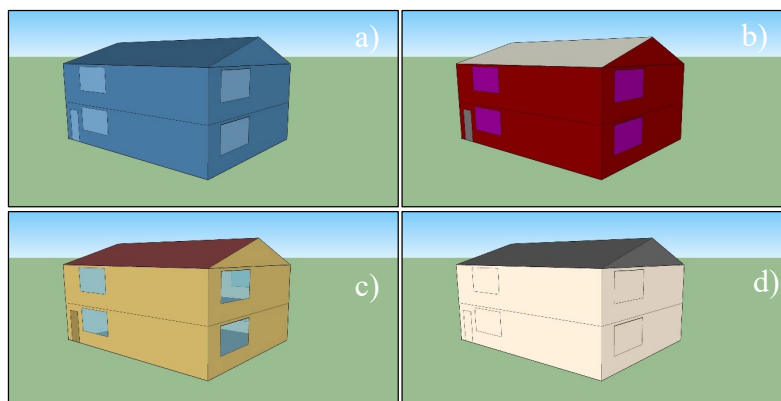

Figure 1. Building model highlighting a) outdoor boundary conditions, b) construction type, c) surface type, d) thermal zones.

For calculation purposes, the building is composed by a single conditioned thermal zone and an unconditioned room at the attic level.

In parallel with the definition of the geometrical and thermal properties of the building envelope, the characterization of internal heat loads is essential for HVAC system sizing and for the energy assessment especially during the summer season. In addition to the occupancy profile of the building, including the number of people and their metabolic activity, the internal heat loads due to electrical equipment and lighting are also defined. The contribution of the internal loads is divided into radiant, sensible and latent heat, the latter where there is a steam production (typically in bathroom and kitchen). The calculation of the cooling load is carried out for the sizing days at the design supply temperature of the air conditioning system in order to maintain the comfort temperature for the thermal zone at 26°C with a RH around 50% [8].

2.3 HVAC system model

The HVAC system is an air system in which there is a gas heating coil and a direct expansion cooling coil whose operation is the focus of this study. Therefore, the system serving the modelled thermal zone is composed of an air loop with a variable volume fan in blow through configuration and the two coils described above. Its operation is assisted by a dedicated outdoor air system (DOAS) responsible for the air changes necessary to maintain good indoor air quality. The HVAC system is represented in the following Figure 2.
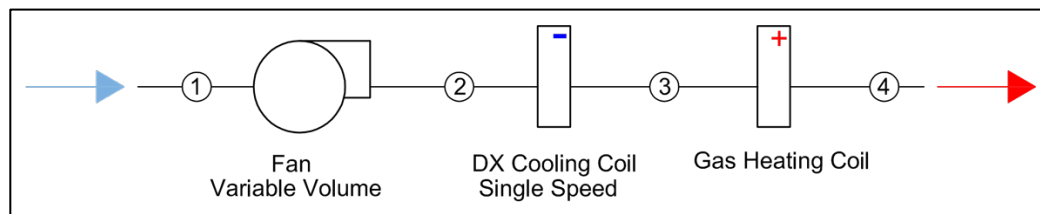
Figure 2. Air loop system model.

The sizing of the main equipment is carried out with respect to the two external climatic conditions inserted for the calculation of the thermal loads, i.e. mitigated and unmitigated, respectively for winter and summer, and to the design conditions for the supply air into the thermal zone for both seasons.

After evaluating the thermal loads in peak conditions and sizing the HVAC systems and the heating and cooling coils thermal power needed, the building thermal-energy analysis focuses on the summer operation of the system. Since the typology of the building is residential, for the operating conditions of the HVAC system a discontinuous mode (on-off) is chosen. Therefore, the activation of the system is expected from morning to evening. The air supply temperature is 10 K lower than the indoor setpoint temperature and so equal to 16°C.

The mathematical model used to represent the operation of the direct expansion cooling coil is based on performance curves obtained from the data declared by the manufacturers. This model is defined as a black-box model in [9], because it does not represent the physical behaviour of the HVAC component.

Starting from the performance data declared, the performance curves are obtained according to the outdoor dry-bulb air temperature at the condenser and the indoor wet-bulb temperature at the evaporator.

As described in detail in [10], the total cooling capacity and the energy input ratio (EIR) modifier curves, which are function of temperature, are quadratic curves with two independent variables: the wet-bulb temperature of the air entering the cooling coil and the dry-bulb temperature of the air entering the air-cooled condenser coil. The output of these curves is respectively multiplied by the rated total cooling capacity and the rated EIR to give the total cooling capacity and the EIR at the specific entering air temperatures at which the direct expansion coil unit is operating.

The biquadratic curves for the total cooling capacity and the EIR are represented respectively in Equation 1 and Equation 2.

$$TotCoolCap = a_0 + a_1X + a_2X^2 + a_3Y + a_4Y^2 + a_5XY \qquad (1)$$

$$EIR = a_0 + a_1 X + a_2 X^2 + a_3 Y + a_4 Y^2 + a_5 XY \qquad (2)$$

Where X and Y represent the two variables and a_i the coefficients of the curves to be determined. The generated curves are then processed to ensure that the curve value is 1.0 at the rated condition established by AHRI [11]. The goodness of curve fit is represented by the statistical parameters R^2 which is the ratio of the sum of the squared deviations of the curve fit values from the mean to the sum of the squared deviations of the manufacturer data from the mean. The best R^2-values are closer to 1.

**Table 1.** (a) Total cooling capacity modifier curve parameters and (b) performance data.

| Total cooling capacity modifiec curve		Performance Data:			
0.9979	R Squared	**Indoor Air Wet-Bulb Temperature**	**Outdoor Air Dry-Bulb Temperature**	**Gross Total Cooling Capacity**	**Compressor Plus Outdoor Coil Fan Power**
Biquadratic	Curve type				
TotCoolCap	Name				
1.0301960331	Coefficient a_0 Constant	°C	°C	kW	kW
-0.0288990678	Coefficient a_1 X	13.89	23.89	6.78	1.30
0.0020749809	Coefficient a_2 X^2	16.67	23.89	7.28	1.31
0.0033473744	Coefficient a_3 Y	17.22	23.89	7.44	1.31
-0.0000561771	Coefficient a_4 Y^2	19.44	23.89	8.07	1.32
-0.0004424811	Coefficient a_5 XY	22.22	23.89	8.93	1.33
13.89	Minimum Value of X	13.89	29.44	6.55	1.50
22.22	Maximum Value of X	16.67	29.44	6.98	1.51
23.89	Minimum Value of Y	17.22	29.44	7.13	1.51
51.67	Maximum Value of Y	19.44	29.44	7.73	1.52
0.7363	Minimum Curve Output	22.22	29.44	8.55	1.53
1.2123	Maximum Curve Output	13.89	35.00	6.30	1.74
		16.67	35.00	6.65	1.74
Temperature	Input Unit Type for X	17.22	35.00	6.80	1.75
Temperature	Input Unit Type for Y	19.44	35.00	7.37	1.75
Dimensionless	Output Unit Type	22.22	35.00	8.15	1.76

3. Results

The thermal energy model simulation during summer has concerned the months of June, July and August and the results for the two different scenarios (i) unmitigated and (ii) mitigated are evaluated in terms of electrical power required for compressor operation and energy efficiency ratio (EER) of the air conditioner. The EER is evaluated as the ratio between the total cooling capacity supplied (thermal energy supply) and the energy consumption of the compressor (electrical energy demand).

The comparison of the results of the two scenarios shows how, in the mitigated scenario, the microclimate mitigation makes the climatic conditions more favourable for the operation of the air conditioner, by reducing the temperature difference between the hot and cold sinks with a significant increase in the system energy efficiency.

Figure 3 shows the electrical power demand of the compressor of the direct expansion system on an average hourly basis. In this graph it is possible to observe the decrease in the demand for electrical power in the mitigated scenario throughout the simulation period, i.e. from June to August. In addition, Figure 4 depicts the variation of EER in both scenarios during the hottest week of July. For the mitigated condition, the EER during the middle hours of the day remains higher than the EER of the unmitigated condition. Finally, the increase in the EER implies a decrease in cooling consumption as shown in the graph in Figure 5 for the three summer months analysed, i.e. June, July and August. The reduction in energy demand for the building analysed with on/off operation mode is equal to 526 kWh, corresponding to a percentage cooling energy saving equal to 18.7%.
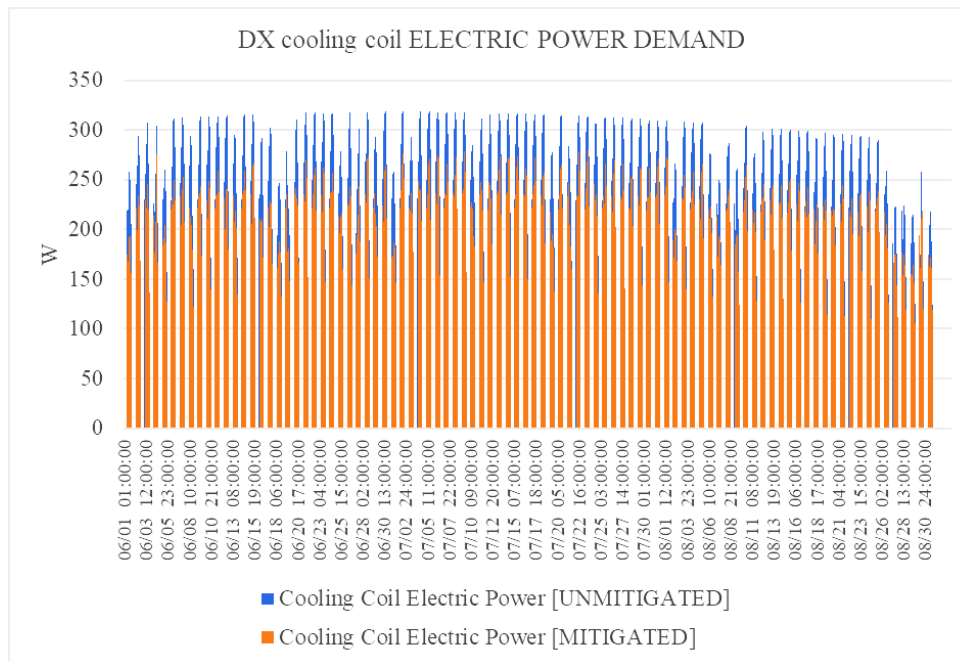
**Figure 3.** DX Cooling Coil **e**lectric power demand.
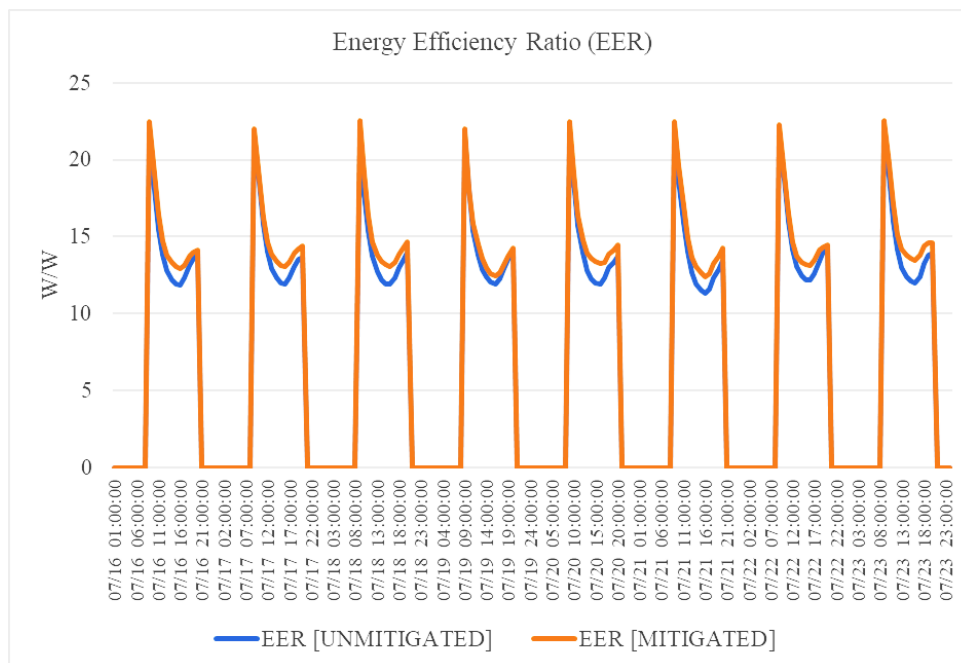
Figure 4. DX Cooling Coil **e**nergy efficiency ratio.

4. Conclusions

In this work, the influence of outdoor microclimate mitigation strategies implemented at settlement level is assessed in terms of building energy saving benefits associated to direct expansion system working conditions showing the goodness of achievable results. In conclusion, the effects of microclimate mitigation have beneficial effects on the summer operation of direct expansion systems. In particular, in the present analysis, the combination of cool, green, and water-based microclimate mitigation techniques, quantitatively accounted for in the mitigated weather file used in building dynamic simulation, allows the direct expansion system to operate under favorable conditions. This involves the

achievement of energy savings for the HVAC system up to 18.7% of the total building cooling energy demand during summer season.
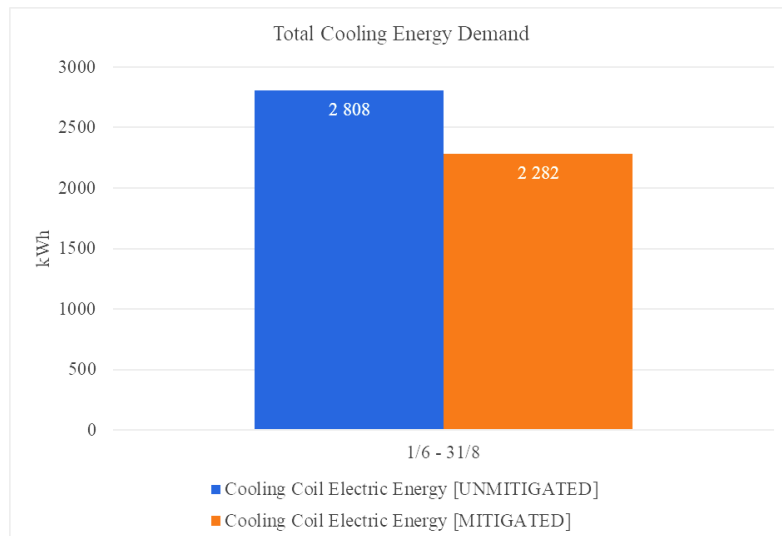
Figure 5. DX Cooling Coil energy demand (June, July and August).

Acknowledgements

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