Outdoor human comfort and climate change.
A case study in the EPFL campus in Lausanne

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Abstract

The increase of the world population and the climate change are drastically impacting people's health and behavior: a sustainable urban planning should propose solutions to reduce the energy demand of buildings and increase the outdoor human comfort in the built environment. Following this idea of sustainable the present paper analyses the energy demand of the EPFL campus in Lausanne (Switzerland) and the outdoor human comfort for actual and futures climatic scenarios (IPCC 2,050 and 2,100). The outdoor human comfort is analyzed with the Actual Sensation Vote (ASV) and the COMFA* Budget, showing the impact of climate change in the outdoor comfort of pedestrian for two different locations on the campus: an open square and a bocce court with cherry trees.

The future thermal behavior of the existing campus buildings in 2,050 underlines an average increase of cooling demand and decrease of heating demand; to reduce the total energy demand of buildings two hypothetical refurbishments of the site, according to Swiss Minergie and Minergie-P labels, are proposed. The analysis of the outdoor human comfort shows the impact of the increasing outdoor temperature in people's wellbeing: according to ASV in 2,050 cool/cold events will be reduced by 40% and warm/hot events will increase by 20%. This trend is confirmed in future scenarios 2,100: in scenario A2 the warm/ hot hours will double (1,316 hours) compared to actual climatic scenario. The analysis realized with COMFA* shows the impact of vegetative surfaces on the outdoor human comfort for several climate change scenarios (2,100): during the summer time the hours of discomfort will drastically increase by 73% in the open square, and just by 55% in the bocce court. Finally a refurbishment of the campus and passive cooling strategies are proposed to reduce the energy demand of the campus and decrease the hours of discomfort of pedestrians.

Keywords: outdoor thermal comfort, comfort research methodology, urban energy simulations

1. Introduction

The increase of urban population and climate change are drastically impacting human's wellbeing and health, by changing in frequency and intensity of weather events, by increasing surface temperature and by decreasing available potable water [1] [2]. This paper proposes a methodology to study how the microclimate and the analysis of the outdoor human comfort in the built environment can influence the future city design. The methodology makes use of an Urban Energy Modelling tool called CitySim [3] to define the energy demand of buildings and the outdoor conditions, considering the energy exchange between pedestrians and the urban microclimate. Two biometerological indices are selected for this analysis: Actual Sensation Vote (ASV) [4] and COMFA* budget [5] both calculated with outputs of the software CitySim.

The model EPFL campus in Lausanne (Switzerland) is analyzed as case study; in previous research the dynamic energy model of the site were developed and validated with on-site monitoring: the buildings energy demand (correlation factor R^2=0.89) and the BiPV power plant model for the solar electricity produced on the EPFL buildings roofs (correlation factor R^2=0.93). The model was then analyzed -according to the International Panel of Climate Change (IPCC) [6]- in three different future scenarios (B1, A1B and B2) for 2,050 [7].

Based on this computational model, this paper presents the analysis of the outdoor human comfort in two different outdoor environments: the square near the Swiss Tech convention center and a bocce court. The model is analyzed in actual and future climatic scenarios (2,050 and 2,100) showing how the thermal perception will vary in the end of the century. Passive cooling strategies are applied in the future outdoor environment, able to decrease the hours of discomfort of pedestrians, according to their metabolic activity. This paper contains the simulations methodology, the simulations results and gives some insights about how to improve sustainability for the future urban design.

2. Methodology

The EPFL campus is located near the city of Lausanne (46°32' N, 06°38' E) in the Vaud canton, Switzerland. The climate of the site is characterized by cold winter (minimal temperature -9°C), warm summers (maximal temperature 30°C) and important rain falls (1,150 mm per year). To analyze the campus energy behavior in 2,050 and 2,100, three different scenarios are envisaged (provided by the software Meteonorm), based on the IPCC studies [6]:

- Scenario B1: rapid growth of population that decline after midcentury, and use of new clean technologies.
- Scenario A1B: rapid economic growth, rapid growth of population that declines after the midcentury and new efficient technology.
- Scenario A2: continue increase of population and reduced research in new technologies.

These scenarios are defined by Meteonorm and contain the projected climatic data for the future: temperature, precipitation and global radiation of the periods 2011–2030, 2046–2065 and 2080–2099 [8].

The future climatic scenarios A2 for 2,050 and 2,100 show an increase of air temperature (minimal temperature -8 °C and -5°C, and maximal temperature 35°C and 39°C respectively) and a decrease of rain falls (total rain falls equal to 1,043 mm and 967 mm respectively) especially during summer months.

2.1 Energy model of EPFL campus and refurbishment scenarios

The Ecole Polythecnique Federale de Lausanne is located near the Leman Lake; the main part of the campus was built between 1972 to 2002 [9] and later buildings were added during the last decade. The geometry of the campus is based on an existing 3D model [10] and the occupancy profile is defined according to SIA 2024/2006 [11]: the number of occupants and their presence is based on the liveable surface of buildings and their function (office, restaurant, classroom and dormitory). The roofs of buildings are covered by photovoltaic panels, with a total power of 2 MW annual and a total area of 12,285 m². The photovoltaic panels were installed in three different phases in 2010, 2011 and 2014 by the electricity carrier Romande Energie. Each phase of construction is characterized by a different types of panel (monocrystalline, polycrystalline, thin film and silicium) and manufacturer [12].

The refurbishment of the site considers the reduction of the energy needs for heating by applying the Minergie and Minergie-P standards to the envelope of all buildings. The Minergie envelope for this case study is characterized by a U-value of 0.16 $W \cdot m^{-2} \cdot K^{-1}$, using 25 cm of Polystyrene insulation (EPS); the Minergie- P envelope has 35 cm of EPS and a U-value of 0.11 ($W \cdot m^{-2} \cdot K^{-1}$); finally the actual windows are replaced by triple glazing windows filled with argon.

2.2 Outdoor human comfort

The outdoor human comfort is analyzed by two biometerological indices: Actual Sensation Vote (ASV) and COMFA* budget. ASV is expressed as a linear equation based on on-site monitoring and questionnaires for several European cities; environmental parameters (air temperature, global radiation, wind speed and relative humidity) are multiplied by a numerical coefficient that varies according to the climate. Considering that the climate in Lausanne can be assimilated to Fribourg (Switzerland), ASV is expressed by:

$$ASV = 0.068T_a + 0.0006R_g - 0.107v - 0.002RH - 0.69 \quad (1)$$

where T_a is the air temperature (°C), R_g is the global solar radiation ($W \cdot m^{-2}$), v is the wind speed ($m \cdot s^{-1}$) and RH is the relative humidity (%). All values are based on hourly meteorological data.

The fundamental equation that describes COMFA* model is [13]:

$$B = M + R_{RT} - C - E - L \quad (2)$$

where M is the metabolic heat generated by a person ($W \cdot m^{-2}$), R_{RT} are short and long wave radiations absorbed ($W \cdot m^{-2}$), C is the sensible heat lost by convection ($W \cdot m^{-2}$), E is the evaporative heat loss through perspiration ($W \cdot m^{-2}$) and L is the long-wave radiation emitted by a person ($W \cdot m^{-2}$).

The thermal sensation scale of ASV and COMFA Budget are defined in Table 1.

Actual Sensation Vote	COMFA Budget ($W \cdot m^{-2}$)	Thermal Sensation
-2	≤ -201	Cold
-1	-200 to -121	Cool
	-120 to -51	Slightly cool
0	-50 to +50	Comfort
1	+51 to +120	Slightly warm
	+121 to +200	Warm
2	≥+201	Hot

Table 1 ASV thermal sensation scale and COMFA budget, as function of thermal sensation.

Pedestrian are modelled with the software CitySim: they are designed as a parallelepiped of 0.17 m side and 1.5 m height; the human body is supposed to be made of four concentric layers: core, muscles, fat and skin [14]. The clothing caracteristics are defined by COMFA* using the intrinsic clothing insulation model, able to vary garments according to the air temperature; finally the metabolic activity of both pedestrians is seated/relaxed, that corresponds to 80 $W\ m^{-2}$. To perform the study two pedestrians were positioned in two different outdoor environment (Table 2): an open square in front of the new Swiss Tech Convention Center (Case study A) and a bocce court (Case study B) protected by three cherry trees (*Prunus Avium*); the Leaf Area Index (LAI) of plants is assumed equal to 3.5 [15] and their albedo equal to 0.22. Fig. 1 shows the location of the square and the bocce court in the EPFL campus; the sites were chosen because are daily frequented by students (eating and leisure) from spring to autumns.

Type	Density ($kg \cdot m^{-3}$)	Specific heat ($J \cdot kg^{-1} \cdot K^{-1}$)	Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	Albedo
Case study A Open square with asphalt ground	580	800	0.75	0.1
Case study B Bocce court with clay soil	1600	890	0.25	0.3

Table 2 Thermal properties of the soils in the two selected sites, data defined according to [16]

Fig. 1 EPFL plan with the location of both case studies (red dots). Photos of the case studies: case study A (center) and case study B (right)

3. Results and discussion

3.1 Energy model of EPFL campus and refurbishment scenarios

Fig. 2a shows the 3D model of the campus with photovoltaic panels (colored in grey) and the annual solar irradiation (short-wave, expressed in $kWh \cdot m^{-2}$). Fig. 2b shows the energy demand for heating: buildings AI and SV have the highest energy demand (around 150 $kWh \cdot m^{-2}$) since they host the Life Sciences faculty, with its experimental laboratories that need an important ventilation rate (heated during the winter period) to maintain the correct indoor temperature. New constructions (BC building, Rolex Learning Centre and Swiss Tech Convention Centre) are realized according to Minergie standards: they present a performant envelope and an efficient air exchange system. The EPFL annual heating demand and electricity production by BiPV, defined in this paper, are validated with on-site monitoring (correlation factor R=0.89 and R^2=0.93 respectively). Experimental laboratories present wide differences between model and monitoring, because of their powerful equipment and high ventilation rate; for example in buildings ELG and ELH the difference between simulation and monitoring data rises up to 26%.

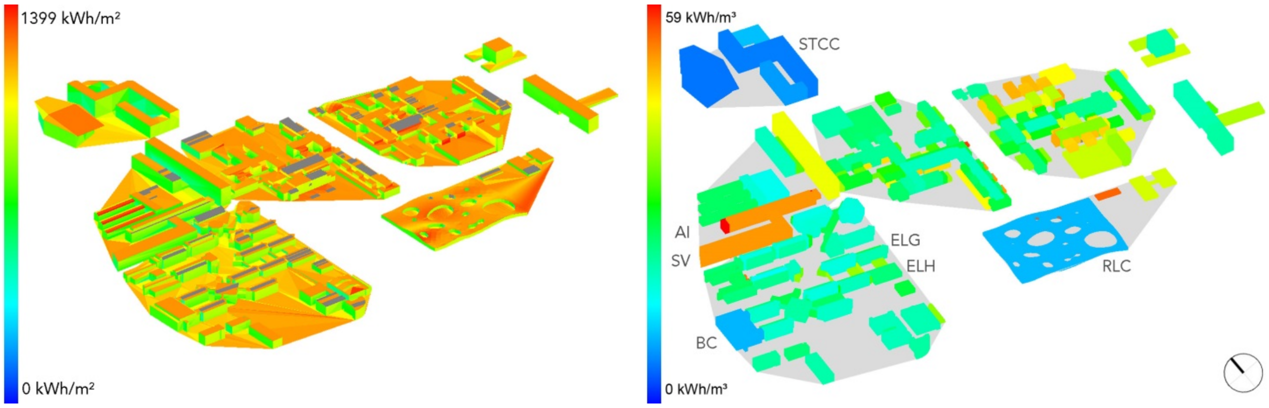

Fig. 2 (a) Annual solar irradiation on the campus, with PV geometry on the roofs (grey). (b) Annual heating demand of the campus, expressed in ($kWh \cdot m^{-3}$). STCC: Swiss Tech Convention Center; RLC: Rolex Learning Center.

The refurbishment of the site, according to Minergie and Minergie-P scenarios, shows an average reduction in the heating demand by 38%, and 44% in the Minergie-P. The future thermal behavior of the existing campus in 2,050 underlines an average increase of cooling demand (5,700 MWh today and 12,300 MWh in 2,050 average) and decrease of heating demand by 15%.

According to climate change, the best option for the EPFL will be the Minergie-P scenario 2050-B1 (increase of cooling demand by 50% and decrease of heating demand by 89%, referring to the existing scenario).To reduce the energy demand for cooling two passive strategies are applied: natural ventilation during nighttime and smart blind strategies: according to these strategies the total energy demand is 25 GWh, lower than existing (37%) and Minergie scenario (17%) for the same climatic data.

3.1 Outdoor human comfort

The outdoor climate of the EPFL in actual and futures climatic scenarios is firstly defined with ASV considering the thermal sensation during all year (day and night) for the climate of Lausanne, without any differentiations concerning the local microclimate. Results are summarized in Fig. 3, showing the comfort behavior in 2,050 and 2,100 as function of the total hours of the year, equal to 8,760. According to actual weather data half of the year is characterized by cool/cold sensations and half is comfortable with less than 700 hours warm/hot. In 2,050 there is a first decrease of cool and cold event by 4% and an increase of warm and hot events by 20%. In future scenarios 2,100 the difference is higher: cool/cold sensations are replaced by warm/hot events, with a peak in scenario A2, where warm/hot hours will double (1,316 hours).

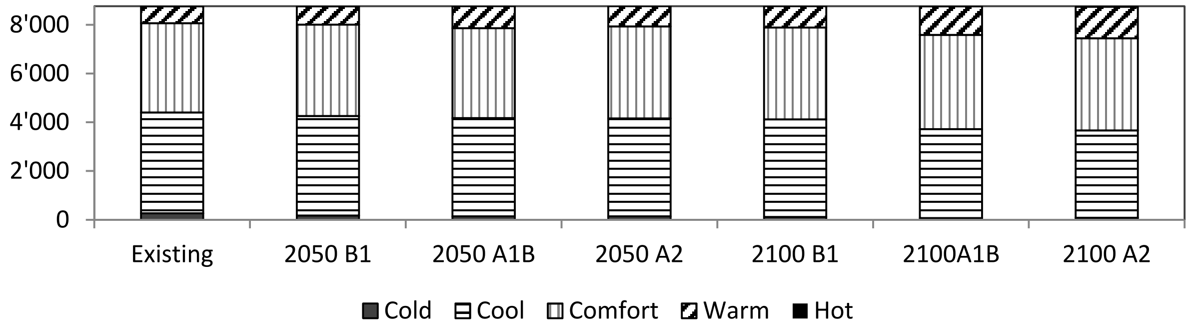

Fig. 3 Actual Sensation Vote in the EPFL campus in actual and future climatic scenarios: 2050 B1, 2050 A1B, 2050 A2, 2100 B1, 2100 A1B and 2100 A2

Considering that the human comfort will be highly impacted in 2,100 scenarios, the COMFA* model is applied for these weather conditions, showing the impact of microclimate (open square and bocce court) in the outdoor human comfort. The input data from CitySim, until now, neglects the evapotranspiration process from trees and grass. COMFA* budget is calculated for all the year, but the results presented are related to day time hours (from 8 am to 7 pm), assuming that both locations are used especially during working hours. Fig. 4 shows the annual solar irradiation (from 0 to 1,264 kWh m^{-2}) in both locations according to actual climatic data; in the open square the shadowing produced by the buildings around is drastically visible: it halves the solar irradiation received by the pedestrian located near building compared to the other positioned at the center of the square.

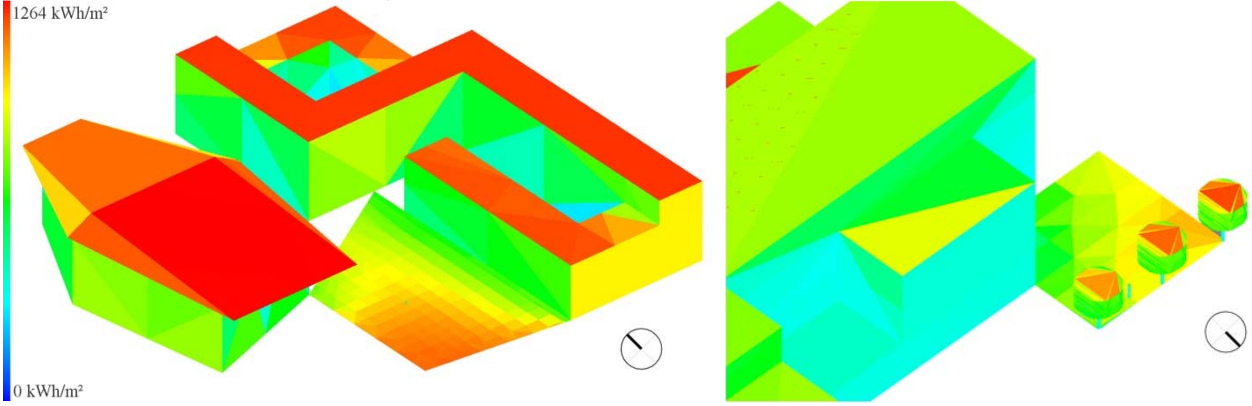

Fig. 4 Annual solar irradiation on the Swiss Tech site (left) and in the bocce court (right). Maximal solar irradiation equal to 1,264 kWh·m^{-2}.

The results shows that the bocce court is more comfortable than the Swiss Tech, as is protected by cherry trees' shadows and presents a ground covered by clay soil that do not absorb and stock the same quantity of heat such as asphalt. Fig. 5 summarizes the outdoor human comfort in actual weather scenario, considering a pedestrian located in case study A and B during a typical spring and a summer day. During a spring day, a pedestrian located in the bocce court will perceive a slightly warm thermal sensation during the hottest hours of the day (from 11 to 15 hours) it feels comfortable for remaining daytime and slightly cool during the night. In the open square near the Swiss Tech a pedestrian will feel slightly warm to warm for the main part of the day and slightly cool during the nighttime. During a summer day the difference between both locations is less intense, but during the hottest hours of the day (from 12 to 14) a pedestrian in the open square will feel hot (maximum COMFA* budget equal to 222 W·m^{-2}) such as in the bocce court will be warm.

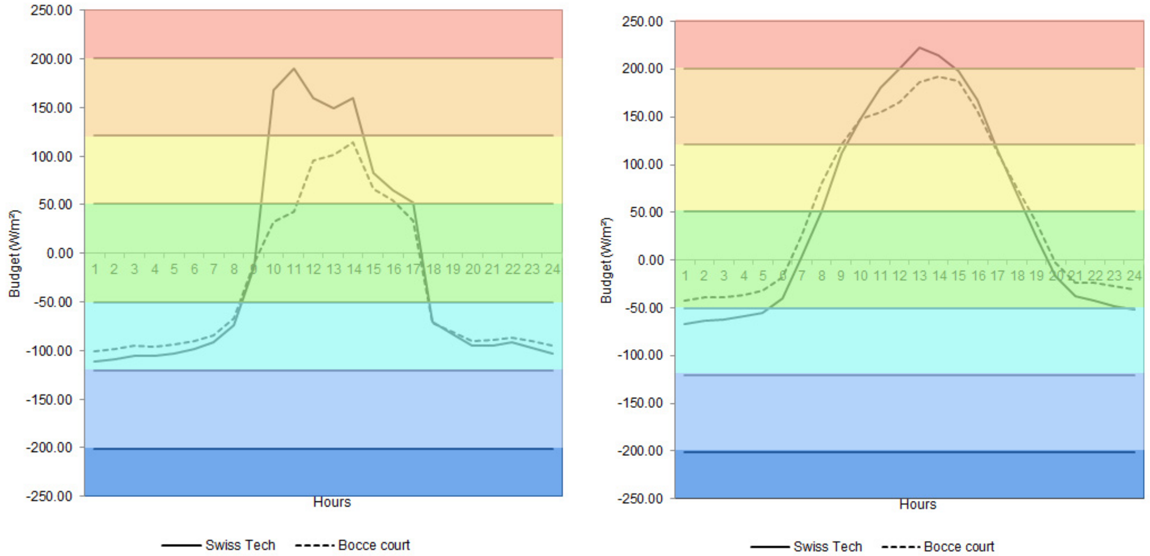

Fig. 5 COMFA Budget for a pedestrian located in the open square near the Swiss Tech, and in the bocce court. Analysis of the human comfort for a spring day (left) and a summer day (right).*

The outdoor human comfort will vary with climate change: the general trend shows a decrease of annual daytime hours of comfort, a slightly increase during the winter time (warm winters) and an important decrease during the summer time (heat waves phenomena). The outdoor human comfort in summer time near the Swiss Tech in 2,100 (average between both scenarios equal to 58 hours of comfort) will be halved compared to the actual climatic scenario (127 hours); this difference is partially linked with future temperatures of the site (average air temperature in summer time will increase by 5°C) and partially linked to geometry and materials of the site. According to simulations performed the climate change will impact more the comfort of pedestrian located in artificial environment, such as the open square near the Swiss Tech, than pedestrian located in a semi natural environment, such as the bocce court, with trees and natural soil. In winter and autumn time the hours of comfort in the bocce court will averagely increase by 9% and 12% respectively, on the contrary in the open court they will increase by less than 2%. On the contrary during the summer time the hours of discomfort will drastically increase by 73% in the open square, and just by 55% in the bocce court. This situation is related to the outdoor activity: if people in case study A would perform high metabolic activity (like running or playing sport, with a metabolic intensity equal to 220 W m^{-2}) the hours of comfort in future climatic scenario for the summer time would be reduced to 9 hours for the entire season.

Shadowing strategies to reduce the hours of discomfort in both locations can be proposed (see Fig.6): three layers of white mashes, selective brise soleil (sloped according to the incident angle of sun) and trees (one *Piecea Rubens* or two *Betula Utilis*).

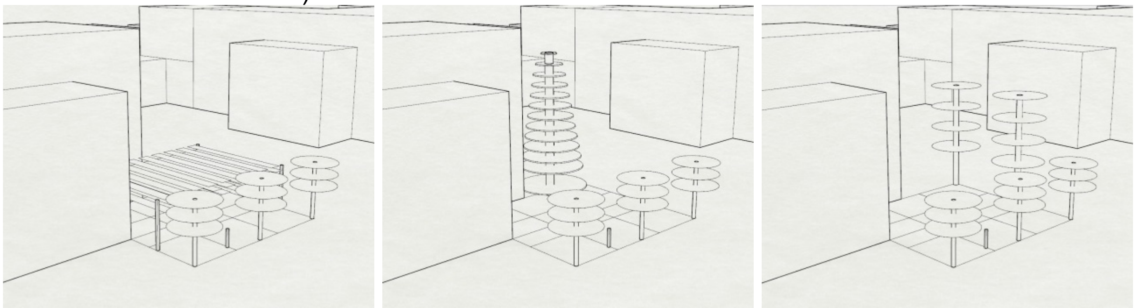

Fig. 6 Proposed shadowing strategies for Case Study A2: textile meshing (left), one Picea Rubens on the South side of the court (center) and two Betula Utilis on the West side of the court (right)

Fig. 7 shows the solar irradiation during the month of July, in Case study B with both trees combinations in 2,100 A2: the solar irradiation received by the ground is averagely reduced by 17% (*Betula Utilis*) and 9% (*Picea Rubens*), the ground temperature is lower and the outdoor human comfort is consequently improved.

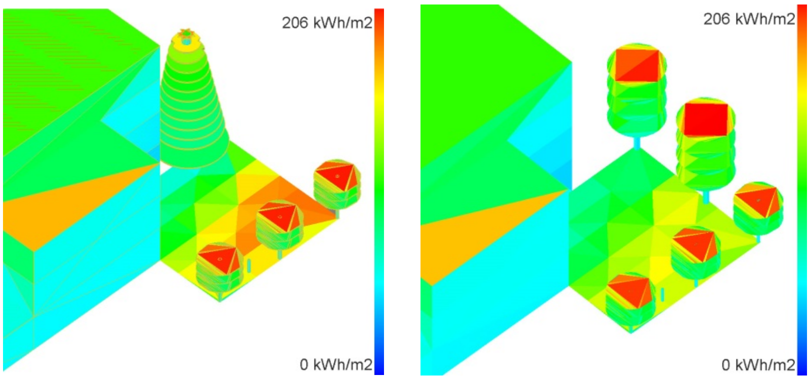

Fig. 7 Monthly solar irradiation (July) in case study B with future climatic data 2,100 A2. Shadowing strategies: Piecea Rubens positioned on the South side of the court (left) and two Betula Utilis on the West side of the court (right)

4. Conclusions

This paper presents a preliminary study on the EPFL campus of Lausanne, showing the energy demand and the outdoor human comfort for actual and future climatic scenarios (IPCC 2,050 and 2,100). The future thermal behavior of the existing campus in 2,050 underlines an average increase of the cooling demand and decrease of the heating by 15%. To reduce the cooling demand a refurbishment of the campus is suggested: if all buildings of the site will be refurbished according to Minergie-P, the cooling demand will increase by 50% and the heating demand will decrease by 89% (both data are referred to the existing scenario).

The outdoor human comfort follows the same trend: according to Actual Sensation Vote in the actual weather scenario, half of the year is characterized by cool/ cold sensations, and half is comfortable with less than 700 hours of warm/hot sensation. In 2,050 there is a first decrease of cool/ cold events by 4% and an increase of warm/ hot events by 20%. In future scenarios 2,100 the difference is higher: cool/cold sensations are replaced by warm/hot events, with a peak in scenario A2, where warm/ hot hours will double (1,316 hours). The analysis realized with COMFA* shows the impact of vegetative surfaces on the outdoor human comfort: in winter and autumn time the hours of comfort in the bocce court will averagely increase by 9% and 12% respectively, on the contrary in the open court they will increase by less than 2%. During the summer time the hours of discomfort will drastically increase by 73% in the open square, and just by 55% in the bocce court.

According to the simulations, places actually used by students for creative activities during daytime will be more comfortable during the cold seasons, but during summer they will became too hot: this phenomenon shows a need to rethink our actual outdoor environment, by proposing shadowing devices and cooling strategies in the vulnerable locations. This problem is addressed by adding textile mesh and proposing a tree design, using natives' plants as *Piecea Rubens* and *Betula Utilis.* The tree model is defined without considering the evapotranspiration from leaves surface: this calculation will be implemented in futures studies.

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