IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: M C Ness *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **352** 012066

Building Bioclimatic Design in cold climate office buildings

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Abstract. Building Bioclimatic Design (BBCD) understands architecture as a filter between outdoor climate and indoor comfort. This way, it encourages the exploitation of freely available climatic resources, before adding any HVAC system. Therefore, BBCD represents a fundamental strategy for improving energy efficiency in buildings. The climate / comfort comparison in building design determines the passive strategies that are most suitable for a specific climatic context, as well as the level of architectural complexity. In cold climates, it would suggest the use of compact shapes and extremely airtight and insulating envelopes, in order to minimize heat losses while maximizing solar heat gains. However, when combined with high internal gains, these measures might cause overheating problems in the warm seasons. That is the case of office buildings, where cooling equipment is included as default even in cold climates, drastically increasing their energy consumption. It is therefore becoming a necessity to consider here the adoption of passive cooling strategies once identified with warmer climates. The aim of this research is to explore how the theories and tools for BBCD could be applied to cold climate office buildings. In order to study the effect of the different climatic contributors, we will use Building Performance Simulation to analyse relevant cases with EnergyPlus (in combination with DesignBuilder). This will in turn help drawing suggestions on how to adapt the Building Bioclimatic Chart (BBCC) for its application to cold climate office buildings in practice. It is well known that the earlier we apply the measures for energy efficiency, the greater their effect and with higher degree of integration. The BBCC is used in the pre-design phase to determine the most suitable passive strategies for climate adaptation and control, informing the design as early as possible along the process. This study can contribute to the development of zero emission neighbourhoods in cold climates, by improving the energy efficiency of their buildings. Additionally, it complements the existing research in BBCD by extending its application to cold climates and office buildings.

1. Introduction

Building Bioclimatic Design (BBCD) understands architecture as a filter between outdoor climate and indoor comfort [1]. In order to determine how this filter should work, it is necessary to understand the local climate, how it interacts with the building, and what our comfort needs are. BBCD encourages the exploitation of useful climatic resources before adding mechanical systems (HVAC) to further correct the indoor climate, thus representing a fundamental step for improving energy efficiency in buildings.

Traditionally, the choice of passive design strategies for climate control in buildings was experience-based (vernacular architecture). However, new building morphology, typologies (office buildings), elements and materials are challenging us to move towards research-based approaches. This is the case of the Building Bioclimatic Charts (BBCC). The most extended one is the Givoni-Milne Bioclimatic Chart [2], that studies how to reach thermal comfort within the psychrometric chart. It considers also the potential for expanding the comfort zone by means of different passive design strategies for climate regulation. In later years, Milne [3] developed Climate Consultant at UCLA for the application of the

BBCC to "envelope dominated" buildings (residential, small non-residential, schools) in mild climates.[4]. This way, the focus was on the relationship between the outdoor climate, the indoor comfort and the passive strategies for climate control. In other climates, the envelope becomes more relevant and its effect needs to be accounted for. Then other types of buildings might have more significant internal loads that should be included as well. Despite its limitations, Climate Consultant is the most complete, up-to-date and user-friendly tool for BBCD that we can find today.

In cold climates, the principles for BBCD would suggest the use of compact shapes and extremely airtight and insulating envelopes, to minimize heat losses while maximizing solar heat gains. However, when combined with high internal gains, these measures might cause overheating problems. That is the case of office buildings, where cooling equipment is included as default even in cold climates, drastically increasing energy consumption. Therefore, the adoption of passive cooling strategies once identified with warmer climates might help increasing both comfort and energy efficiency in these cases [5].

It is well known that the earlier we apply the measures for increasing environmental performance of a building, the greater their effect and with a higher degree of integration. The BBCC is used in the pre-design phase to inform the decisions as early as possible along the process, thus maximizing their effect.

An adapted BBCC for cold climates office buildings could show the passive strategies that are best suited for the indoor climate that is generated by the envelope, including also the effect of internal loads. In this way, it would complement existing research in BBCD by extending its application, earlier limited to residential buildings in warmer climates. At the same time, it could be used to reflect on the climatic consequences of choosing different envelopes, occupancy density, equipment and lighting systems.

This paper is part of a doctoral thesis on BBCD in cold climates office buildings, financed by the Faculty of Architecture and Design at NTNU and the Research Centre on Zero Emission Neighbourhoods in Smart Cities.

2. Purpose

The aim of this research is to explore how the theories and tools for Building Bioclimatic Design could be applied to cold climate office buildings to make them more sustainable.

The existing theories and tools for BBCD look at the local climate to study when the building in question will provide thermal comfort and how to extend the comfort zone to the rest of the hours, by means of passive strategies. Originally developed for warm climates, it does not include the effect of the building envelope in creating an indoor microclimate that can differ substantially from the outdoor climate, especially with highly insulating and airtight solutions. Therefore, it would suggest primarily passive heating strategies for cold climates, even though in practice those very buildings might be experiencing overheating problems.

On the other hand, there exist cases of office buildings in cold climates that make extensive use of passive strategies both for heating and cooling. Some of those, like the Baumschlager-Eberle 22/26 in Lustenau, Austria [6], has managed to substitute the conventional HVAC system for a set of passive strategies combined with sensors and automated control of the window opening and lighting system. These cases show the need to update the existing theories and tools for BBCD, to accommodate for the lessons learnt from practice. Accordingly, the BBCC should include the indoor microclimate created by the envelope (cold climates) and the internal gains (office buildings), prior to the study of thermal comfort or the application of passive strategies for climate control. Once updated, the BBCC could be used on other buildings to improve their energy efficiency and comfort through passive design, prior the implementation of active systems.

3. Method

In order to study the effect of the different climatic contributors to the indoor microclimate, we used Building Performance Simulation (BPS) to analyse two relevant cases. This helped drawing suggestions on how to adapt the Building Bioclimatic Chart for its application to cold climate office buildings in practice, thanks to a systematic parametric analysis.

The choice of BPS tools fell on EnergyPlus/DesignBuilder because of the level of accuracy, transparency, adaptability and complexity, in combination with an intuitive user interface.

The case analysed is based on Baumschlager-Eberle 22/26 (BE2226) because of its representativeness, being a rather extreme example of design optimization for cold climate, with maximal use of passive strategies. Furthermore, the availability of detailed measurements on-site made it possible to calibrate the model to resemble reality more accurately.

Then, the same model was used for two different locations with slightly different type of cold climate, in order to see how it would respond to diverse conditions. First, it was analysed in the original location, Lustenau (Austria), with a cold-temperate humid continental climate with warm summers and 2980 heating degree days (HDD). Next, it was moved to Oslo (Norway), with a cold humid continental climate with cool summers and 4428 HDD. For the original location at Lustenau, the weather file was obtained by interpolation from Meteonorm [7], while the one for Oslo was taken from the EnergyPlus site [8], corresponding to the weather station at Fornebu.

The building is conformed as a cube of around 24m long sides, with a high degree of compactness (c=1.08). In includes six floors, each with a free height of 3.4m (4.4m in the ground floor) to allow for a good air stratification, thus allowing for the used air to stay close to the ceiling and keeping the occupied volume fresher. The windows are vertical and almost from floor to ceiling, to provide with a good daylight distribution throughout the space. The envelope consists of two layers of Porotherm 38, a lighter one outside for a better insulation and a heavier one inside for structural stability and thermal mass. The rendering is with lime plaster, which helps sealing the envelope from the outside and regulating the indoor air humidity and CO2 concentration. It uses concrete slabs with glass fibre reinforced concrete rendering for the floor and lime plaster for the ceiling, ensuring the exposure of its thermal mass. Besides, it has a very open floor distribution, using secondary spaces as partitions, which keeps a clear path for air distribution, while increasing the thermal mass.

A simple model of the whole building was created for BPS analysis (figure 1), to then calculate the indoor microclimate in the open office on the second floor (figure 2).

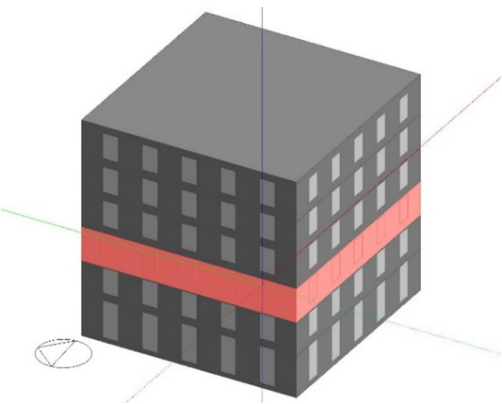

Figure 1. Axonometry of the whole office building (Design Builder)

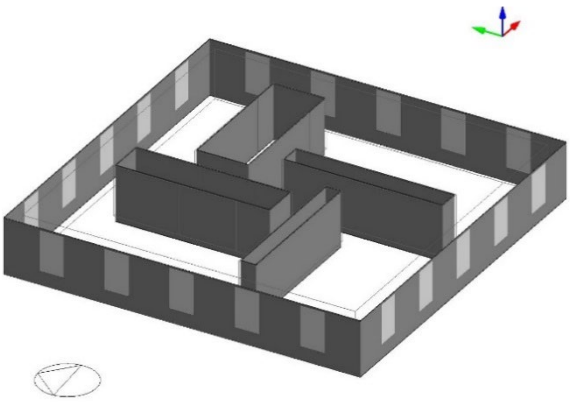

Figure 2. Model of the open office on the 2nd. floor (Design Builder)

The most relevant characteristics for the materiality of the building envelope (insulation, thermal mass and airtightness) are specified in table 1.

Table 1. Characteristics of the building envelope

wall	U-value (W/m2 K)	0.138
	Internal heat capacity (KJ/m2 K)	85.760
	Infiltration rate (ac/h)	0.040
window	U-value (W/m2 K)	0.7
	Solar transmittance factor	0.55

The internal gains for the open office on the second floor are specified in table 2. The occupancy density is rather low because of the necessity of leaving a free circulation perimeter by the façade to avoid discomfort due to draft when opening windows. The equipment consists mainly on one computer and two screens per person. As for the lighting, it corresponds to the best practice in Design Builder.

Table 2. Internal gains

Occupancy density (people/m2)	0.05
Equipment (W/m2)	11.50
Lighting (W/m2)	3.30

The simulations were carried out in different steps of complexity for the internal loads, in order to quantify the changes in the indoor microclimate for each one of them. In this way, it was done first for the empty building, to obtain the effect of the envelope alone. Next was added the occupancy, then the equipment and finally the lighting system (with response to occupancy and minimum illuminance levels 400 lux).

The indoor temperatures obtained from the simulations were then presented in two different ways. In relation to time (figure 5), to show seasonal and daily fluctuations, the amplitude of its variations and the proximity to the targeted comfort range of 22-26°C. In relation to humidity, on the Psychrometric chart, to reflect the total scattering of climatic values, thermal comfort zones for summer and winter with the percentage of hours of discomfort, and potential for extending these comfort zones using passive strategies (figure 6).

4. Case I: Office building in Lustenau (Austria)

Sited by the river Rhine, Lustenau lays on the north side of the Alps, 10 km away from the lake Constance. It is located at 47°N and 9°E, with an elevation of 404m. With an average temperature of -0.6°C for the coldest and 19.6°C for the hottest month, the climate in Lustenau is classified as Cfb, cold-temperate humid continental with warm summer, in the Köppen-Geiger scale [11]. With 2980 HDD (18°C) annually, it belongs to the ASHRAE climate zone 4A (borderline with 5A) [12].

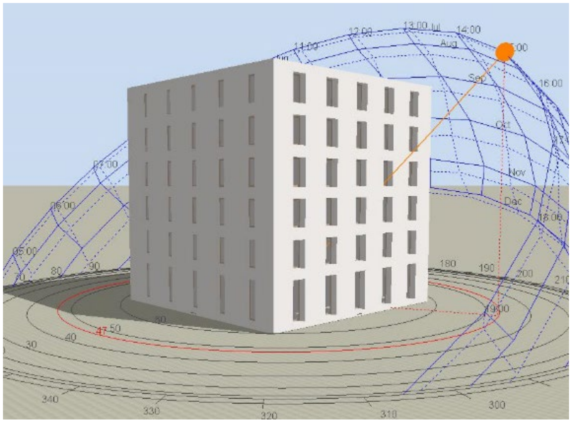

Figure 3. Sun path for Lustenau and shadows for 15th June at 15:00 (Design Builder)

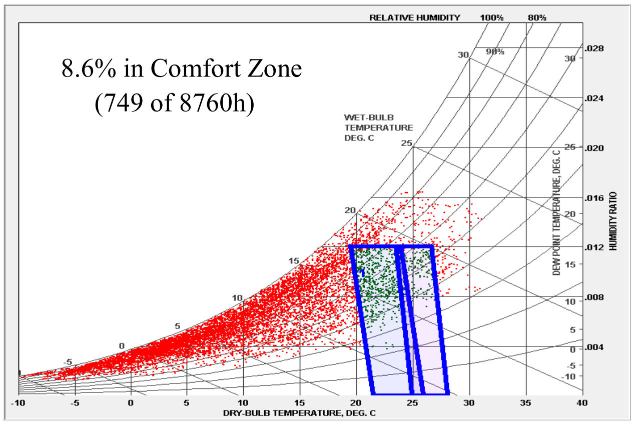

Figure 4. Hourly climatic values for Lustenau. Psychrometric Chart with thermal comfort zones for summer (right) and winter (left). (Climate Consultant)

When plotting the outdoor climatic values for Lustenau into the Psychrometric chart, only 8.6% of them fall inside the comfort zone, being most of them on the heating side of it (figure 4).

We can see in figure 5 the thermal stability created by the envelope, thanks to a combination of high insulation levels and thermal mass, though temperatures are too low throughout the year. It also creates a time lag in its thermal response to outdoor conditions. The addition of occupancy warms up the space,

IOP Conf. Series: Earth and Environmental Science **352** (2019) 012066 doi:10.1088/1755-1315/352/1/012066

so that they reach more comfortable temperatures during the summer and early autumn. After adding the equipment, temperatures experience a higher daily variation and fall within the comfort range for the mid-seasons, while there appears overheating in summer. Finally, the lighting system increases daily variations and creates an important overheating problem, reaching temperatures of more than 50°C.

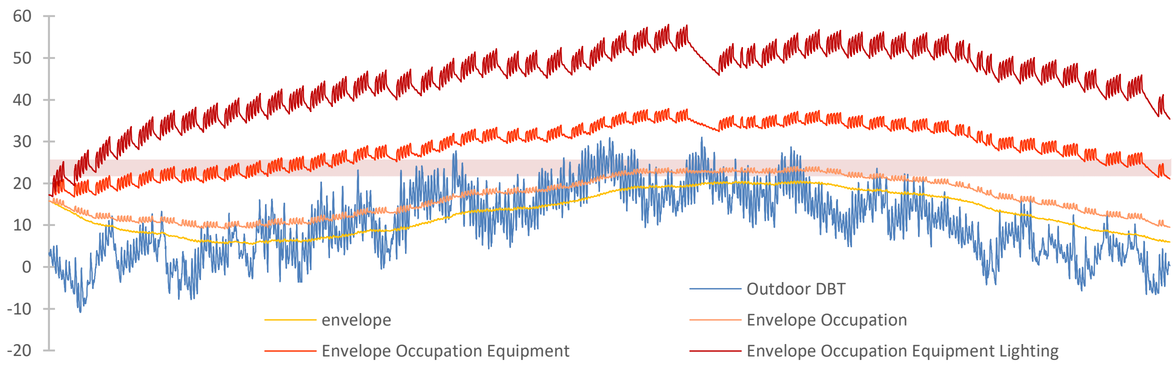

Figure 5. Annual variations in indoor temperature (°C), with cumulative internal loads. Case I, Lustenau.

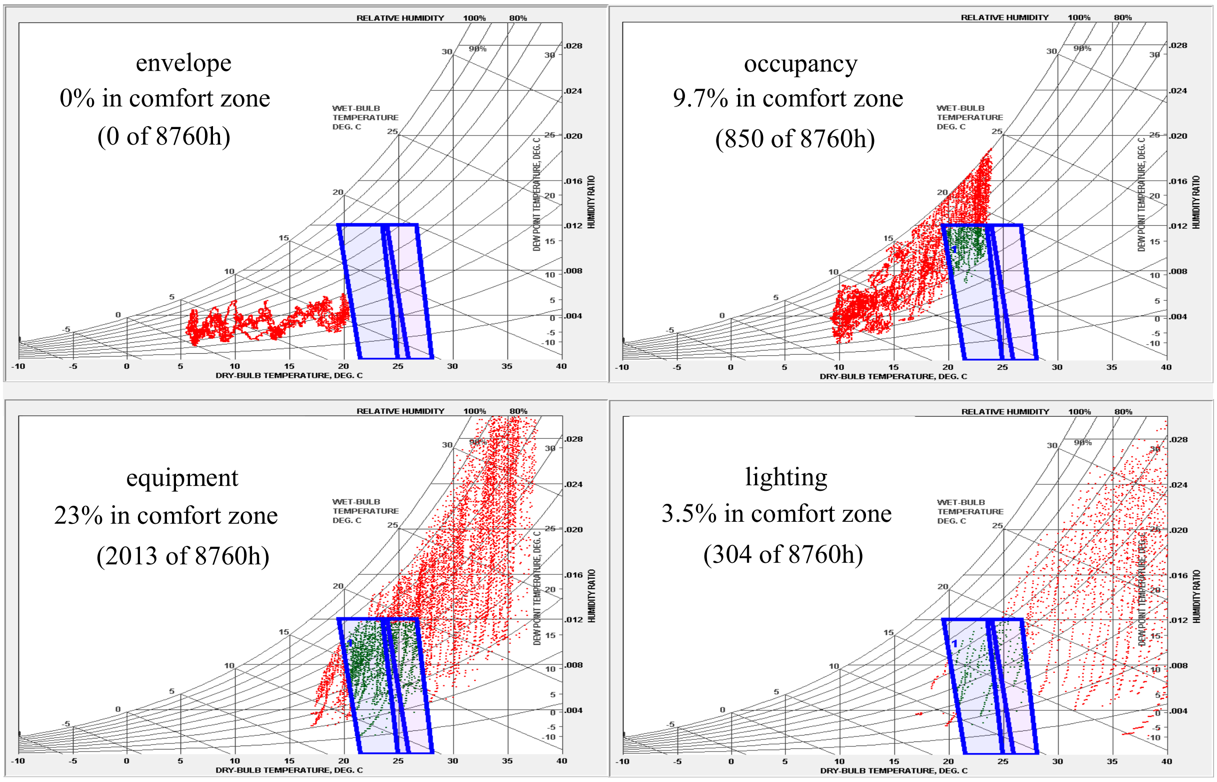

Figure 6. Psychrometric charts with thermal comfort zone for summer (right) and winter (left), for cumulative internal loads. Case I, Lustenau.

The Psychrometric charts (figure 6) clearly show the effect of the envelope in grouping the climatic points into fewer and tighter values, though all of them fall on the heating side of the comfort zone. Then there occurs again more scattering of the values, the more gains we include. At the same time, the indoor climate becomes warmer, with important overheating after adding lighting gains.

5. Case II: Office building in Oslo (Norway)

Oslo lays on the northern side of the wide Oslofjord, in the Southeast of Norway, at 59°N and 10°E, with an average elevation of 23m. The mean temperature of the coldest month is -3.8°C, 17.5°C for the hottest, which gives a cold humid continental climate with cool summer, Dfb in the Köppen-Geiger scale [11]. It is in climate zone 6A according to ASHRAE classification [12], with 4428 HDD (18°C). Having a higher latitude, the sun is lower in the horizon. This means that even though outdoor temperatures are lower throughout the year, solar gains through windows will warm up interior surfaces and increase indoor temperatures. Besides, there are fewer hours of sun in winter and more in summer, which could accentuate overheating risk in the warm season and not provide so much heat in the cold one, when it is most needed (figure 7).

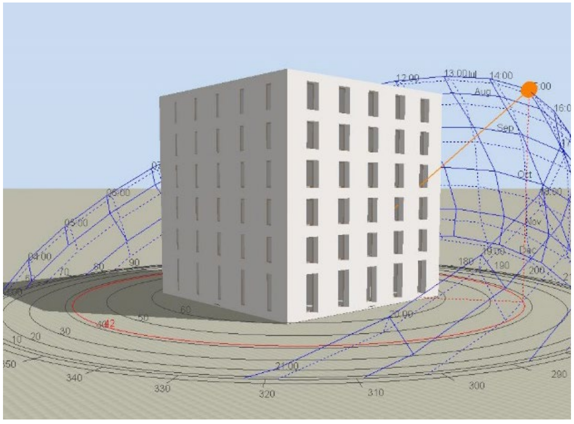

Figure 7. Sun path for Oslo and shadows for 15th June at 15:00 (Design Builder)

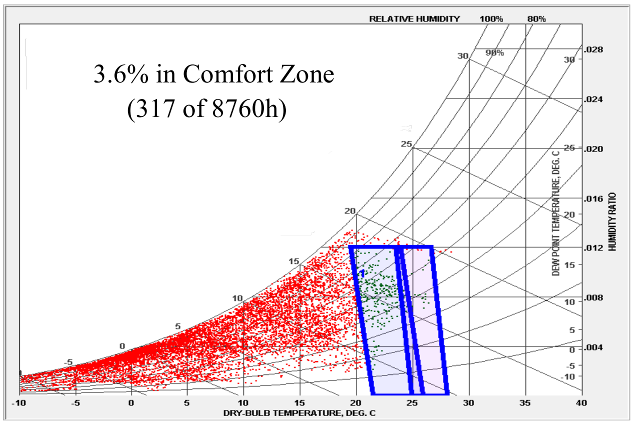

Figure 8. Hourly climatic values for Oslo. Psychrometric Chart with the thermal comfort zones for summer (right) and winter (left). (Climate Consultant)

When plotting the climatic values into the Psychrometric chart, only 3.6% of them fall inside the comfort zone, being most of them on the heating side of it (figure 8)

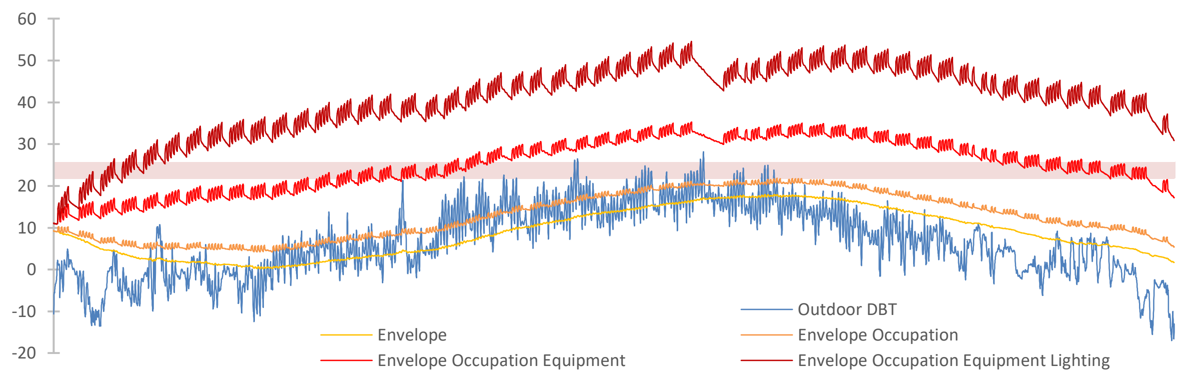

Figure 9. Cumulative variations indoor temperature (°C) through time, with internal loads. Case II, Oslo.

We can see in these graphs (figure 9) the thermal stability created by the envelope, though staying below comfort in a similar way as in Lustenau.

In the same way as for case I, in case II a moderate increase of temperature due to the internal loads is positive, bringing the curve towards more comfortable temperatures. In contrast, the total increase in indoor temperatures after adding all the internal gains can cause some important overheating problems.

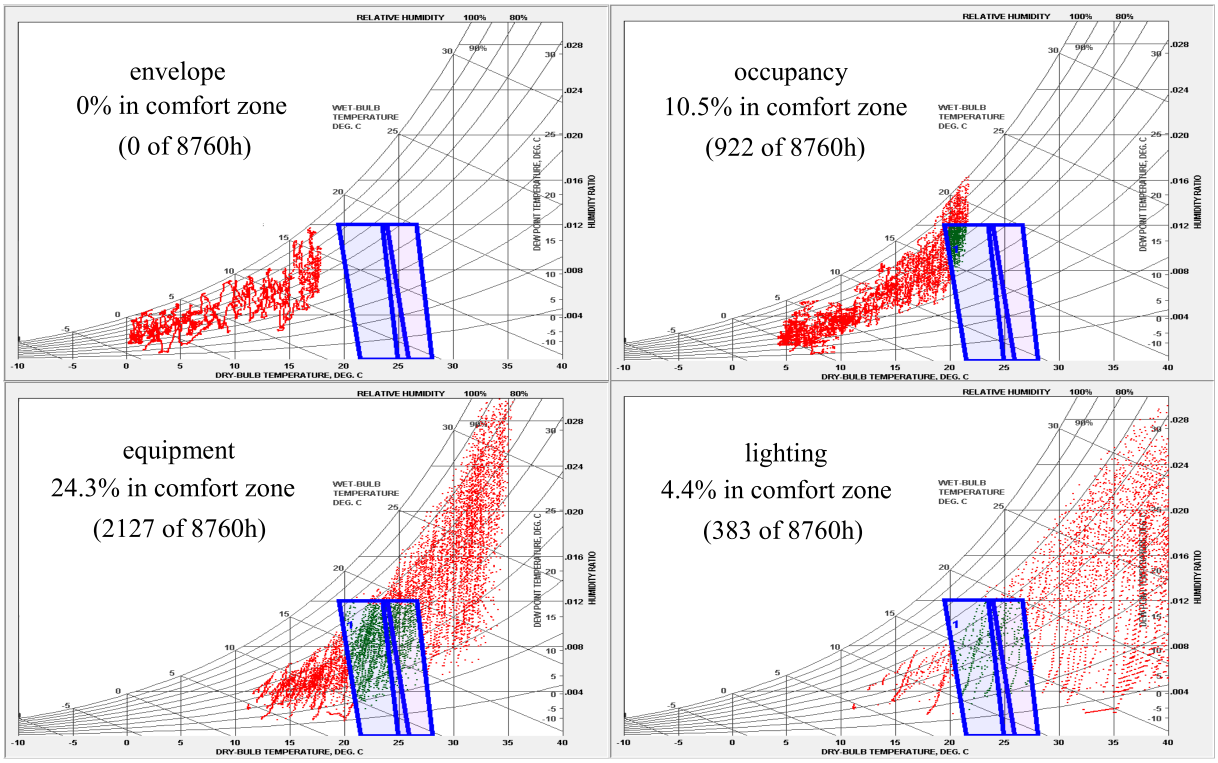

Figure 10. Cumulative psychrometric charts with the thermal comfort zone for summer (right) and winter (left), for the internal loads in case II, Oslo.

The Psychrometric charts (figure 10) show the same grouping effect of the envelope into fewer and tighter values, though all of them fall outside the comfort zone, in a similar way as they did in Lustenau. The more gains we include in the model, the more scattering of the climatic points. At the same time, the indoor microclimate becomes warmer, moving towards the right in the chart, with important overheating after adding the lighting gains. Again, it clearly shows the benefits of first bringing the climatic points closer to each other (effect of the envelope buffering extreme values) and then warming up with moderation (internal gains), in order to bring as many points as possible into the comfort zone.

6. Discussion

Comparing the psychrometric charts for the outdoor and indoor climate (figures 4 and 6 for Lustenau, 8 and 10 for Oslo), it becomes clear the relevance of considering the effect of the envelope and internal gains, for office buildings in cold climates. The climatic points change their distribution completely from the original outdoor values, with a quite homogeneous cloud on the cool side of the comfort zone (CZ) and 8.6% (case I) to 3.6% (case II) of the values inside it. After including the envelope, the indoor climatic points conform more like a path with a much lower variability and amplitude of temperatures (combined effect of insulation and thermal mass), still on the cool side of the CZ and now 0% inside it. Then, after adding the internal loads, the points get progressively more scattered and move towards the warm side of the CZ, with a growing percentage inside it but also an increased risk of overheating. Finally, once all the internal gains are included, the climatic values appear to be very spread, with a high amplitude in temperature and humidity, being most of them on the warm side of the CZ and only a very small percentage of them inside it (3.5% in case I, 4.4% in case II). The combined effect of the envelope and the internal gains changes the indoor climate from a cold one with a clear need for heating, into a hot one with and important need for cooling. This could be compensated by the use of an adequate set of passive cooling strategies, including natural ventilation and solar shading.

In figures 5 and 9, on the other hand, it is easy to appreciate the effect of the envelope in restricting the thermal variability of the indoor climate. In addition, it creates a time lag in the seasonal variations, with a delay in the warmer period. This delay allows a non-coincidence between the peak in solar gains and in outdoor temperatures, to soften their effect indoors. Thanks to the stabilizing effect of the envelope, daily fluctuations of the outdoor climate do not have much effect indoors, while changes in occupation become very relevant. It is easy to appreciate the cumulative effect of internal gains during working days, as well as the cooling effect of empty nights and weekends, and even more for the summer holidays. The operational schedule for internal gains is therefore as important as their thermal load.

The most challenging aspect in Building Bioclimatic Design is the uncertainty generated due to the occupancy (density, distribution), the complexity of the physical environment and the climate (daily and seasonal variability, climate change). Even so, despite the uncertainties and difficulties, it is important to acknowledge and utilise the potential within BBCD.

7. Conclusion

The main findings of this study show the magnitude of the microclimate that is generated in the building thanks to the envelope, with its materiality and design. Its effect is further enhanced by the addition of internal gains, transforming the original need for heating that corresponds to cold climates, into a severe need for cooling. This has lately been translated into the installation of mechanical cooling systems by default, thus increasing considerably the energy use of office buildings. On the other hand, the implementation of passive cooling strategies like natural ventilation or solar shading could help increasing their energy efficiency while improving thermal comfort.

An adapted BBCC for cold climate office buildings could significantly reduce the amount of energy and resources used nowadays in conditioning this kind of buildings, while increasing indoor comfort.

Further research is needed though, in order to quantify the effect of different types of envelopes. The indoor climate will change depending on the level of insulation, the airtightness and the thermal mass. Window size, geometry and orientation are also relevant for the incident radiation and the daylight availability, which influence the need for artificial lighting and the thermal gains. Furthermore, internal loads become more relevant for the indoor climate with a more stringent envelope. Since they depend directly on occupancy, appliances and operation, these parameters gain more importance in this type buildings and should be considered as part of their design strategy. Finally, the inclusion of a smart control system could finetune the operation of the building to respond more efficiently to changes in the climate or the occupancy, representing the active system to operate the building elements to ensure a comfortable indoor climate.

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