LOW-ENERGY BUILDINGS WITH NIGHT VENTILATION AND AIR-TO-AIR HEAT EXCHANGERS - CASE STUDIES AND ANALYSIS

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ABSTRACT

This study presents some results from a monitoring project with night ventilation and earth-to-air heat exchanger. Both techniques refer to air-based low-energy cooling. As these technologies are limited to specific boundary conditions (e.g. moderate summer climate, low temperatures during night, or low ground temperatures, respectively), water-based low-energy cooling may be preferred in many projects. A comparison of the night-ventilated building with a ground-cooled building shows major differences in both concepts.

KEYWORDS

low-energy cooling, night ventilation, earth-to-air heat exchangers, ground cooling, thermo-active building systems, energy performance, monitoring, data evaluation and analysis

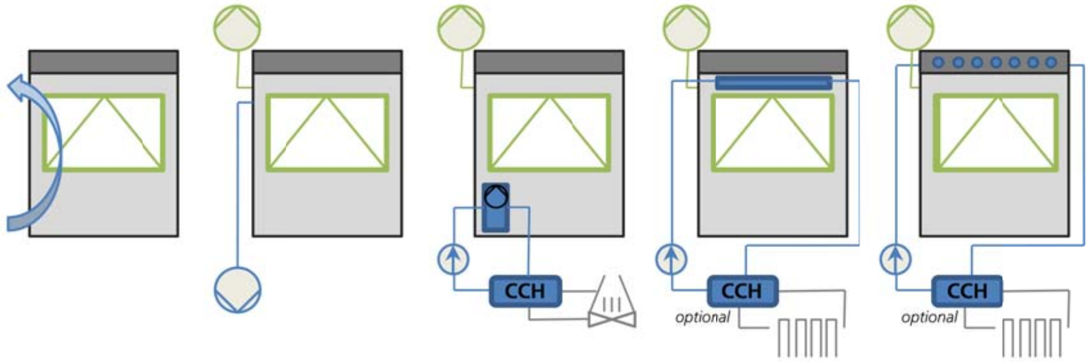
INTRODUCTION

Low-energy cooling is strongly recommended by EPBD §25 [1] in non-residential buildings and has been widely applied to residential and non-residential buildings all over Europe. In recent years many research projects supported the understanding of passive and low-energy cooling techniques. Many reports, guidebooks and tools may be found in Ref. [2], [3] and [4], respectively. This study is strictly based on monitoring data only.

A clear definition of low-energy cooling is still missing. In the context of this study,

- low-energy cooling refers to cooling technologies which mainly use ambient energy heat sinks such as the cool night air or the ground for cooling (in combination with reversible heat pumps).
- These concepts base on passive cooling technologies, e.g. free ventilation, solar shading, reduced internal heat gains and high thermal inertia.
- Mechanical cooling is reduced to a minimum.

Figure 1 gives an overview on different cooling concepts.



vent.	free day vent.	hybrid day vent.	hybrid day vent.	hybrid day vent.	hybrid day vent.
cooling concept	free night ventilation	mechanical night ventilation	hp active cooling w/ fan coil	radiant cooling w/ ceil. panel	radiant cooling w/ TABS
heat sink	ambient air	ambient air	cooling tower	BHEx [8-18]	BHEx [22-6]

Figure 1. Low-energy cooling concepts.

The ThermCo project [5] investigated the potential of different ventilation and cooling strategies with regard to energy efficiency and thermal comfort in different European climates. The results demonstrate a high potential for night ventilation strategies in North-European climate with low ambient air temperatures. In the Mid-European climate, water based low-energy cooling technologies based on radiant cooling make use of the cool ground in summer. Active cooling provides good thermal comfort in South-European climate with high and fluctuating cooling loads. *Figure 2* shows which cooling concept for a typical low-energy office building (according to EPBD requirements) may be favourably applied in different climate zones. Additionally, local specific conditions have to be considered such as microclimate, building design and location.

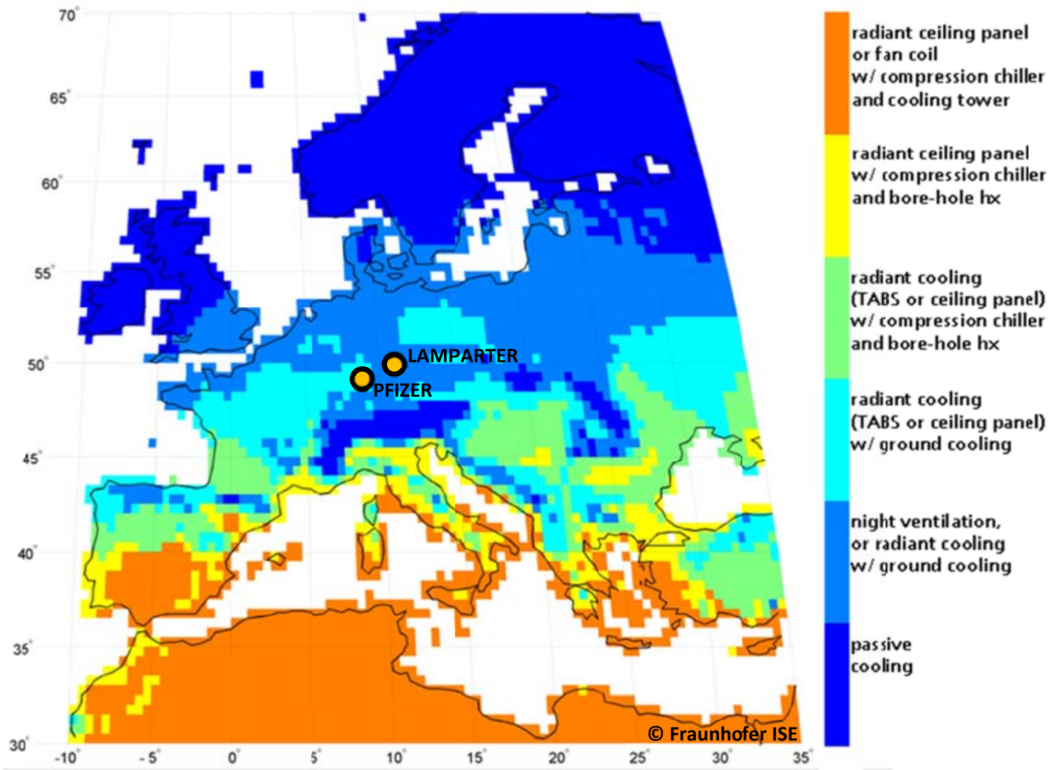


Figure 2. Cooling concepts (from *Figure 1*) in different European climate zones.

METHODOLOGY: ENERGY EFFICIENCY AND THERMAL COMFORT

Energy efficiency is calculated for the overall systems based on monitored data. *Figure 3* shows the adopted methodology for the concept based on night-ventilation [6] and earth-to-air heat excanger [7] and for the water-based low-energy cooling concept [8].

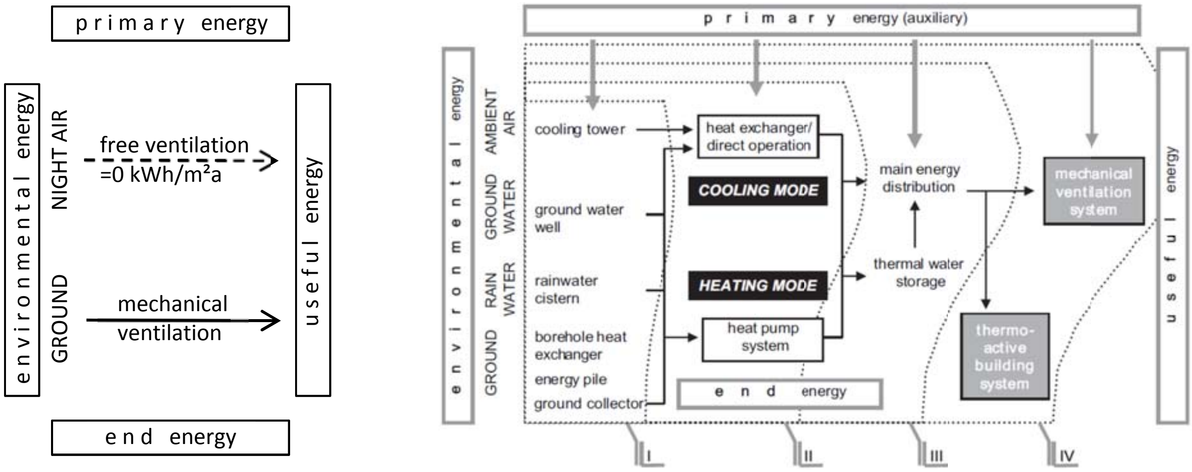


Figure 3. Methodology for the energy and efficiency evaluation.
Left: For low-energy cooling concepts based on night ventilation and earth-to-air heat exchanger.
Right: For water-based low-energy cooling according to four balance boundaries I–IV.

Figure 4 shows a building signature which combines four evaluation criteria (anti-clockwise):

- The energy efficiency is calculated for the useful energy [kWh_{cool}] and the primary energy demand for the whole system [kWh_{prim}] as shown in *Figure 3*. As most low-energy cooling concepts are driven by electricity (e.g. mechanical night ventilation, pumps for ground cooling, or reversible heat pumps), the target value is calculated for best practice systems considering a primary energy factor of 3.0 kWh_{prim}/kWh_{el}. Realised best practice buildings and theoretical calculations show, that low-energy cooling may reach seasonal performance factors (SPF) for the overall system (balance boundary IV) of 20 $kWh_{cool}/kWh_{el,free,IV}$ for free cooling and 5 $kWh_{cool}/kWh_{el,mech,IV}$ for mechanical cooling. As in moderate summer climates the free cooling potential is high, this may result in an overall SPF of 10 $kWh_{cool}/kWh_{el,IV}$ or 3.3 kWh_{cool}/kWh_{prim}, respectively..
- The cooling energy demand [$kWh_{cool}/m^2_{net}a$] characterises the quality of the building envelope and the passive cooling concept. The cooling energy demand should not exceed 20 $kWh/m^2_{net}a$ in moderate or warm summer climate.
- The overall primary energy demand for heating, cooling, ventilation and lighting [$kWh_{prim}/m^2_{net}a$] characterises the building performance, incl. the use of renewables or high-performance HVAC&R components. The primary energy demand should not exceed 100 $kWh/m^2_{net}a$.
- The thermal comfort in passively cooled buildings with free-night ventilation and earth-to-air heat exchanger (LAMPARTER) is evaluated according to the adaptive and in the air-conditioned reference building (PFIZER) according to the static approach in standard EN 15251 [9].

Different building and energy concepts can be comprehensively evaluated by these benchmark numbers.

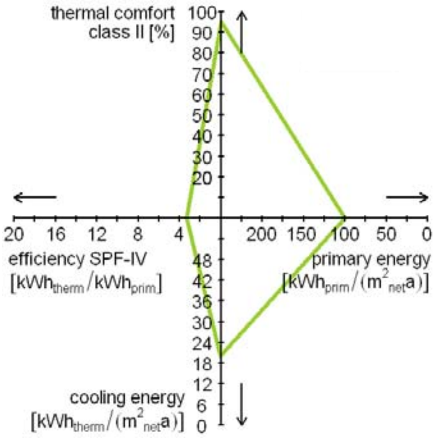


Figure 4. Building signature with target values referring to [8].

NIGHT VENTILATION AND EARTH-TO-AIR HEAT EXCHANGER

Next to the prevailing weather conditions, there are many other boundary conditions with regard to a successful implementation of night ventilation concepts. Textbooks [10], [11]and guidelines [12] give practical information. With regard to this study, microclimate and building concept are the most important specific parameters.

The LAMPARTER building, *Figure 5*, represents a prototypical night-ventilated building in a moderate summer zone (*Figure 2*) The passive-house building is located in a rural area with fresh summer winds from the high plains of the Swabian Alb. The small office building allows for free cross-ventilation. The members of staff (±20 persons) are well-informed about the building concept and, hence, adapt their user behaviour (window opening and external Venetian blinds) according to the indoor and outdoor climate [13]. Furthermore, the night cooling is enhanced by an earth-to-air heat exchanger which was built in the existing excavation (for economic reasons).

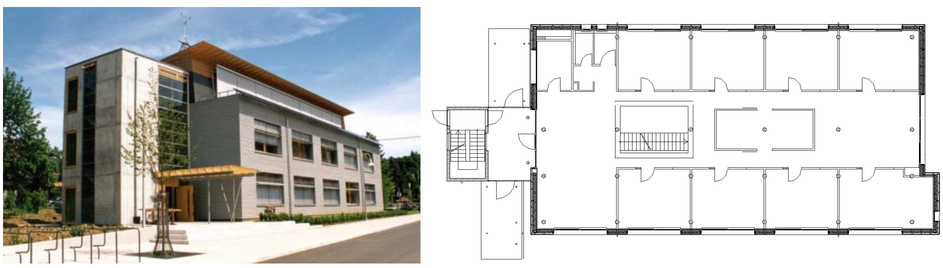


Figure 5. The LAMPARTER Building, Weilheim, Germany. © Hans Lamparter GbR.

Monitoring data and building description are given in Ref. [14]. Figure 6 shows the summer energy concept and the monitored air-change rates.

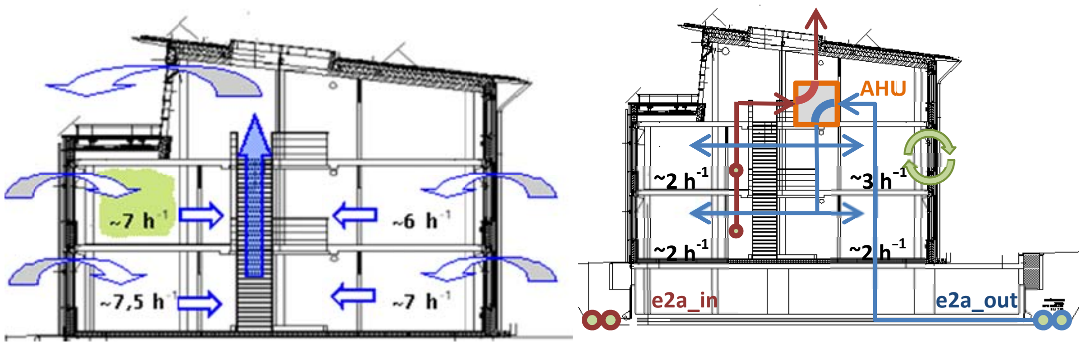


Figure 6. Free night-ventilation and hybrid day-ventilation with earth-to-air heat exchanger.

Thermal Comfort

As the LAMPARTER building is passively cooled, the thermal comfort is evaluated according to the adaptive approach. Noteworthy, the room temperatures exceed more often the lower than the upper limit of comfort class B. Even during the European heatwave in summer 2003, the thermal comfort complies with comfort class B.

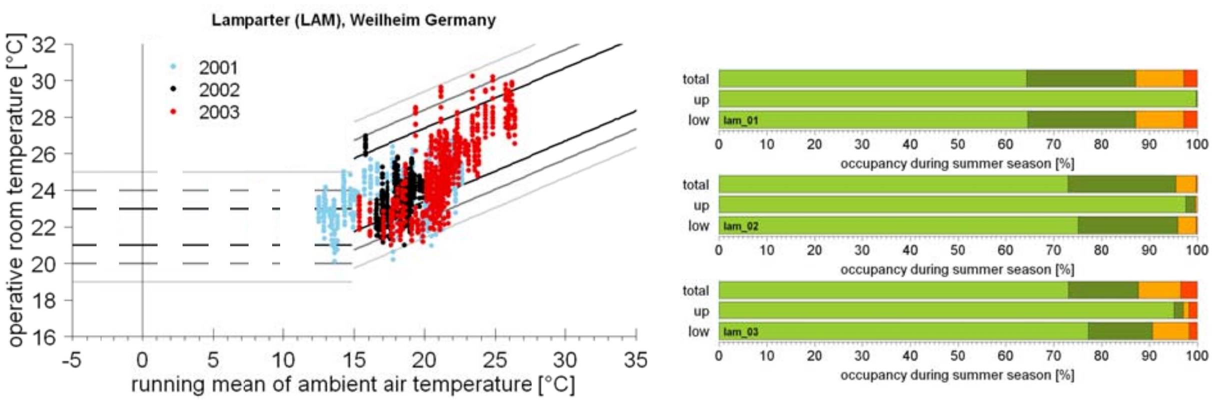


Figure 7. LAMPARTER: Thermal comfort and footprints for three years, summer only.

Energy Efficiency and Building Signature

The cooling energy from free night-ventilation is a function of the temperature difference between inside and outside and cannot be measured. Furthermore, the cooling energy is an implicit function of thermal comfort. Thus, the cooling energy is set to 0 $kWh/m^2_{net}a$ for free-cooling as no mechanical system is needed. The energy efficiency of free night-ventilation is infinite by definition.

Accordingly, the cooling energy is only the cooling energy from the earth-to-air heat exchanger which provides 3.4 $kWh_{cool}/m^2_{net}a$. As the whole mechanical ventilation runs during the daytime to provide the hygienic air-change rate, the additional electricity demand for the operation of the earth-to-air heat exchanger is calculated only for the (very low) pressure drop in the buried pipes. This results in a seasonal performance factor of 53.2 kWh_{cool}/kWh_{el} or 17.7 kWh_{cool}/kWh_{prim}, respectively.

Due to the lean building concept, high performance HVAC components, a daylight concept with controlled artificial lighting and solar power, the primary energy consumption is 50 $kWh/m^2_{net}a$ only.

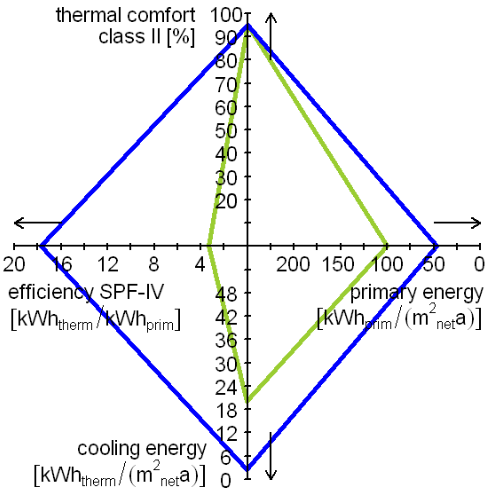


Figure 8. LAMPARTER: Building signature.

GROUND COOLING AND THERMO-ACTIVE BUILDING SYSTEMS

There are many boundary conditions which avoid a successful implementation of a night-ventilation concept. However, a low-energy cooling concept based on ground cooling reduces the primary energy demand significantly compared to a mechanically cooled building. Guidelines [15] and manufacturer information give practical information on the implementation of these concepts.

The PFIZER building, *Figure 9*, represents a typical office and laboratory building in a warm summer zone (*Figure 2*) The retrofit concept is based on passive-house technologies and a low-energy cooling concept. The air-conditioned building is located in an industrial area with poor air change in the Rhine valley. The big building with a sealed façade (labs) does not allow for cross-ventilation and is fully air-conditioned for safety-at-work reasons.

Figure 9. The PFIZER Building, Freiburg, Germany. © Fototeam Vollmer.

Monitoring data and building description are given in Ref. [16]. *Figure 10* shows the heating and cooling concept with the main components in summer operation mode.

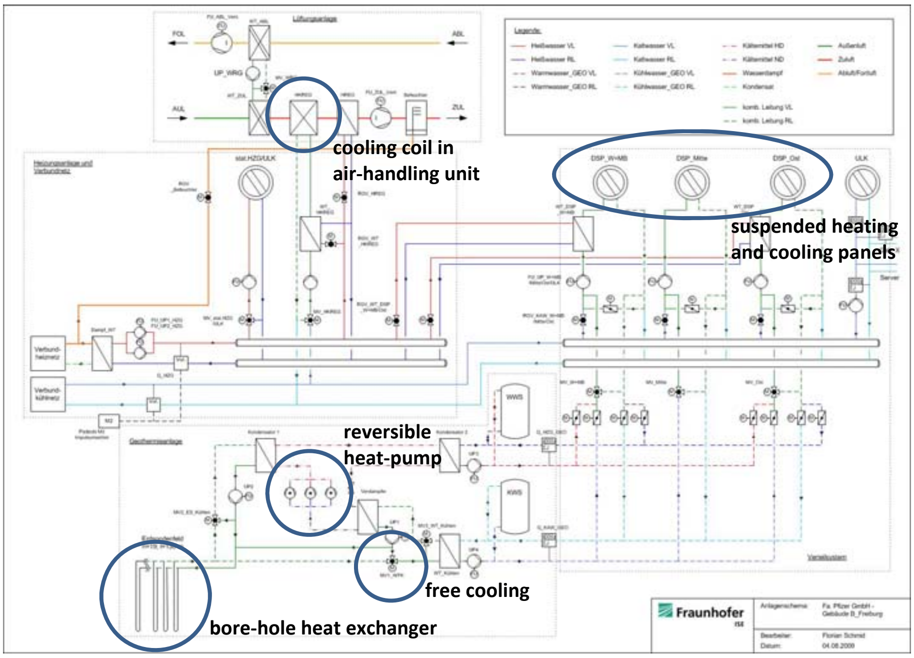


Figure 10. Energy concept with ground cooling, reversible heat pump and thermo-active building systems.

Thermal Comfort

As the PFIZER building is air-conditioned, the thermal comfort is evaluated according to the static approach. Noteworthy, the room temperatures exceed more often the lower than the upper limit of comfort class B, since no summer / winter comfort control was implemented in 2008. (Note: After optimisation, the summer room temperatures are higher today.)

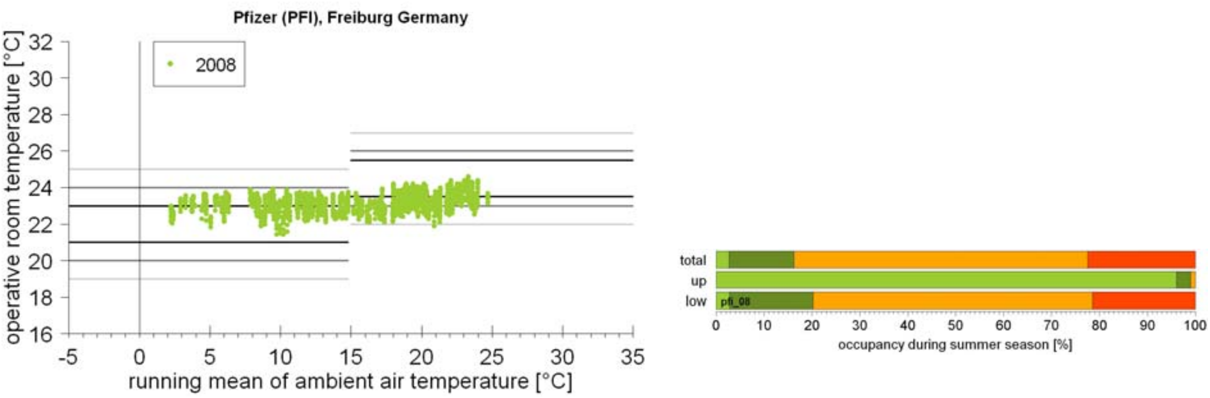


Figure 11. PFIZER: Thermal comfort and footprints for 2008.

Energy Efficiency and Building Signature

The cooling energy demand is 50 kWh/m²$_{net}$a for dehumidification, convective and radiant cooling.

The energy efficiency for balance boundary II (electricity for primary pump and compressor according to the definition of SPF in DIN V 18599 [17]) is 6.9 kWh$_{cool}$/kWh$_{el,free,II}$ in free cooling mode and 5.6 kWh$_{cool}$/kWh$_{el,free,II}$ in mechanical cooling mode. The comparatively small SPF in free cooling mode is due to the low temperatures and the accordingly high volume flow rate which results in a comparatively high energy consumption of the primary pump. The comparatively high SPF in mechanical mode is due to low ground temperatures and high cooling temperatures for the radiant cooling systems. Considering the percentage of operation time in free and mechanical cooling mode and the whole distribution system (secondary pumps and energy losses), the overall SPF_{IV} is reduced to 3.9 kWh_{cool}/kWh_{el} or 1.3 kWh_{cool}/kWh_{prim}, respectively.

This shows clearly the practical limitations of cooling concepts. In spite of high-performance components and a well-designed HVAC&R concept, the overall energy efficiency is considerably lower than the potential SPF_{IV} of 10 kWh_{cool}/kWh_{el}. Nevertheless, this concept is much more energy efficient than a conventional one: A compression chiller / cooling tower with a COP of 3 kW_{cool}/kW_{el} may result in an overall SPF_{IV} of 1.8 kWh_{cool}/kWh_{el} or 0.6 kWh_{cool}/kWh_{prim}, respectively.

The primary energy is calculated for the local energy consumption and production only. Due to high-performance HVAC components, ground cooling with low-temperature thermo-active building systems and heat production from a wood fired boiler, the primary energy consumption is 300 $kWh/m^2_{net}a$. Though this is considerably higher than the target value of 100 $kWh/m^2_{net}a$, it is much lower than the benchmark for laboratories with 800 $kWh/m^2_{net}a$.

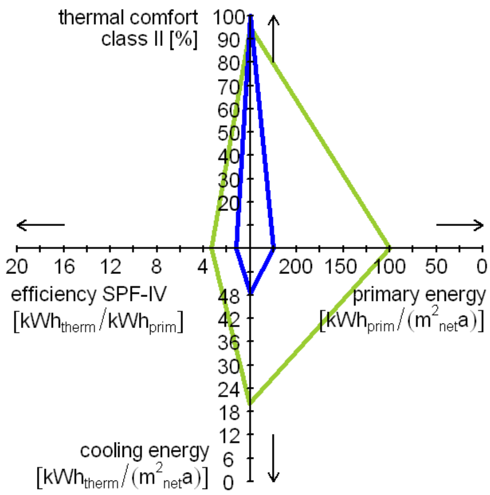


Figure 12. PFIZER: Building signature.

CONCLUSION

Passive cooling with free night-ventilation and earth-to-air heat exchanger provides good thermal comfort with high energy efficiency. However, the practical application is strictly limited to specific boundary conditions such as moderate summer climate, favourably microclimate, or small buildings with high thermal inertia. The whole building design and operation fosters the passive cooling concept.

Though mechanical night-ventilation enhances the heat dissipation compared to free night-ventilation, often a water-based cooling concept may be more reliable and similarly energy efficient and will provide better thermal comfort.

Ground cooling in combination with a reversible heat pump is often a better solution for warm summer climate, locations with inappropriate microclimate or other practical limitations. If thermo-active building systems are used for heat transmission to the room, these systems can be operated with high energy efficiency.

ACKNOWLEDGEMENTS

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