Energy efficient and low CO_2 office building

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Reduction of energy use reduces both the primary energy use and $CO_{2\,eq}$ emissions.

Current office buildings are becoming more and more energy efficient. In particular the importance of heating is decreasing, but the share of electricity use is increasing. When the CO_2 equivalent emissions are considered, the emissions from embodied energy make up an important share of the total, indicating that the building materials have a high importance which is often ignored when only the energy efficiency of running the building is considered. This paper studies a new office building in design phase. The results showed that the reduction of energy use reduces both the primary energy use and $CO_{2\,eq}$ emissions. Especially the reduction of electricity use has a high importance for both primary energy use and CO_2 emissions when fossil fuels are used. The lowest $CO_{2\,eq}$ emissions were achieved when bio-based, renewable energies or nuclear power was used to supply energy for the office building. Evidently then the share of $CO_{2\,eq}$ emissions from the embodied energy of building materials and products became the dominant source of $CO_{2\,eq}$ emissions.

Introduction

The ambition in sustainable development of the built environment is to reduce the harmful impact of the nature of materials and building energy use [1]. Often the building energy use and the minimization of its $CO_{2\,eq}$ emissions are considered to be the desired goal. However, as the energy use decreases the importance of $CO_{2\,eq}$ emissions originating from building materials and products increases. Thus, what kind of materials and building products are used becomes more important [3]. In addition, the minimization of $CO_{2\,eq}$ emissions is perhaps not the only desired target, but we need to consider also the minimization of primary energy use, since it highlights rather well the use of natural resources.

The aim of the study is to

1) Find out the different available options in the design phase in order to minimize the energy consumption;
2) Consider how the $CO_{2\,eq}$ emissions from the embodied energy from building materials and $CO_{2\,eq}$ emissions from energy use in the building should be treated;
3) Consider how we should weight the primary energy use and the $CO_{2\,eq}$ emissions of different design options. In this study is a real office building was studied.

Methods

The studied building is an office building located in Helsinki developed by Skanska Commercial Development Finland. The building was under design phase and the aim was to study different alternatives in order to choose the most energy and environmental efficient way to erect the building. The gross floor area of the nine storey building is 26 000 m². The geometry of the building is quadratic. The studied properties are shown in **Table 1**.

The buildings were modelled in a dynamic IDA simulation environment [2]. The building model was the architect's real 3D model but the building spaces were simplified to 43 different zone models each representing typical uses of the space type, such as office rooms, meeting rooms, cafeteria, etc.

Embodied Carbon in Materials

The embodied CO_2 includes energy consumption of building materials and products, the use of raw materials and greenhouse gases. The most important greenhouse gases are fossil fuel derived CO_2, CH_4 and N_2O.

Table 1. Studied design alternatives. The control systems include ventilation and lightning.

Feature	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Building envelope excl. windows	Building Code 2010	Building Code 2010	Building Code 2010	Building Code 2010	Building Code 2010	Passive house
Windows (W/m²K)	1.0	1.0	1.0	1.0	0.7	0.7
Ventilation heat recovery	70%	70%	80%	80%	90%	90%
LED lighting	in garage	in garage	in garage	in garage	in all spaces	in all spaces
Systems control level	building	room	room	building	room	room

In the 2010 Building Code the U-values for external walls is 0.17 W/m²K, base floors 0.16 W/m²K, roofs 0.09 W/m²K and doors 1.0 W/m²K. The ventilation heat recovery requirement in the 2010 Building Code is 45%, which was not used in calculations, since that was not an option in the design phase. In the so called passive house level the U-values for external walls is 0.08 W/m²K, base floors 0.15 W/m²K, roofs 0.08 W/m²K and doors 0.7 W/m²K.

Table 2. Primary energy factors and CO_2 equivalent emissions used.

	Primary Energy Factor	CO_2 equivalent*
District heating average	1.87	0.22
District heating bio	0.4	0.12
Electricity average	1.87	0.38
Electricity from district heating average	1.87	0.38
Peak electricity from nuclear power	2.8	0
Peak electricity from coal	2.0	0.928
District cooling	0.25	0.12
Green electricity	0.2	0

* Unit: kg CO_2/kWh.

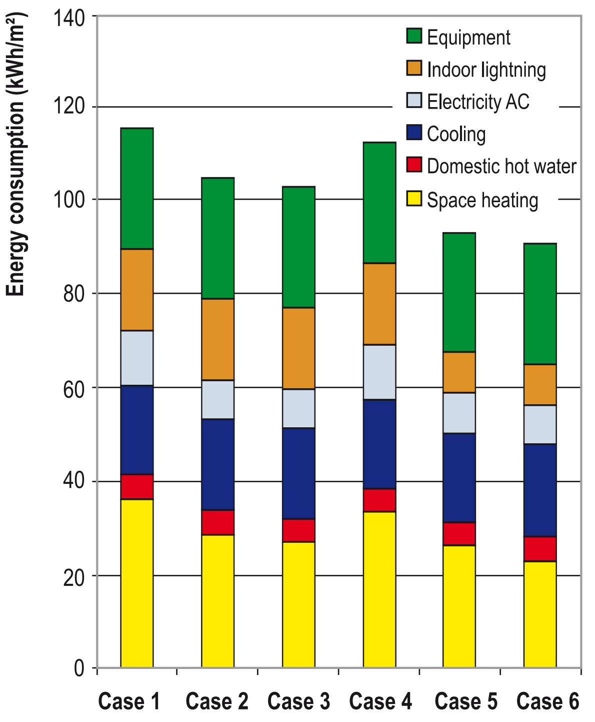

Figure 1. Yearly energy consumption in different cases. Electricity AC represents for electricity for air conditioning systems.

In the calculations the greenhouse gases are transformed to $CO_{2\,eq}$ by using IPCC's characteristic factors.

Energy Sources and their CO_2 Equivalent Emissions and Primary Energy

The studied alternatives for energy and their CO_2 emissions are shown in **Table 2**.

The service life for building was assumed to be 50 years. The embodied CO_2 emissions from building materials and process were estimated according to design drawings.

Results

The energy consumption was highest in the case 1 and lowest in the case 6. But the energy consumption in case 4 was also really high, being nearly the same as in the case 1 and showing that the building level control is inefficient with respect to energy saving. In particular the heating energy consumption is the highest when the control is at the building level. The energy consumption was 20% lower in case 6 compared to case 1. The only difference between cases 3 and 4 was the temperature control. In case 3 the control was at the room level, while in the case 4 the control was at the building level. That resulted in a 7% difference in total energy consumption and a 20% difference in space heating, in addition the difference in cooling was also 20% between those two cases (**Figure 1**). Since in office buildings the electricity use has higher importance than heating, case 6 does not have that much difference in consumption, even though the insulation values are much better (equal to passive house). The major difference between cases 3 and 5 was the LED lightning, in case 5 all lightning was done by LEDs, which clearly resulted in a lower energy consumption.

The Finnish Building code is very advanced with respect to reducing heat losses from buildings; e.g., the U-values and ventilation heat recovery, as well as air tightness of the building envelope, are required to be rather good. This can be clearly seen from the energy consumptions (**Figure 1**). The CO_2 equivalent emissions of heating are also rather low due to the low energy consumption when average Finnish district heating, cooling and electricity are used as energy sources (**Figure 2**). In **Figure 2** heating includes both space heating and domestic hot water.

Due to the low heating energy consumption the embodied CO_2 emissions and electricity are dominant components in the CO_2 emissions. That is actually rather surprising, since case 1 is the typical building code level in new office buildings, and only ventilation heat recovery is clearly better than the average in new buildings. In this study the embodied CO_2 includes energy consumption of building materials and products, and the use of raw materials and greenhouse gases.

Evidently, if all the electricity used is generated from renewable energy sources and for district heating and cooling bio-fuels are used, the embodied CO_2 emissions have the highest share and the over all CO_2 equivalent emissions decrease dramatically (**Figure 3**). However, the problem with renewable electricity is that the power plants produce renewable energy on a yearly basis. Thus, sometimes the electricity might originate from fossil fuels for a short period of a time if not enough electricity from renewable sources is available. The electricity produced by fossil fuels is substituted by renewable energy on a yearly basis to get the balance. Usually this means excess energy, e.g., from wind power.

Figure 4 shows the primary energy consumption as a function of the relation between embodied and energy-derived $CO_{2\ eq}$ emissions. The $CO_{2\ eq}$ embodied corresponds to the $CO_{2\ eq}$ emissions from materials during their lifetime and $CO_{2\ eq}$ energy corresponds the $CO_{2\ eq}$ emissions from energy use in the building (heating, cooling and electricity). When all different options for heating, cooling and electricity sources were compared it can be clearly seen that the nuclear-based energy alternatives all ended up with rather high primary energy consumption and since the building energy use is carbon neutral, the embodied CO_2 emissions become dominant (**Figure 4**).

If low primary energy is the target, then bio-based district heating systems seems to be effective as well as the use of electricity from renewable energy sources. Ground heat or the average local heating performed rather similarly in respect to primary energy use. This is because the ground heating systems use electricity but

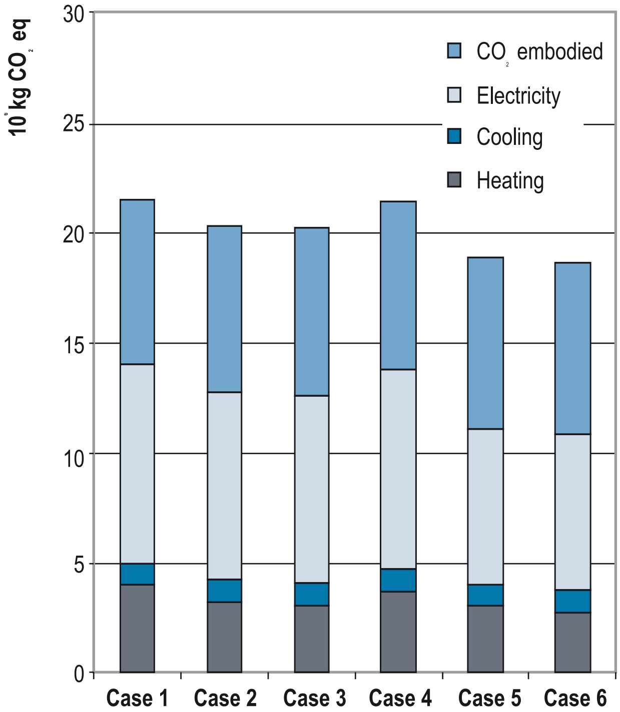

Figure 2. The share of each energy consumption and embodied CO_2 in different cases when average district heating, cooling and electricity are used. The heating includes both space heating and domestic hot water heating.

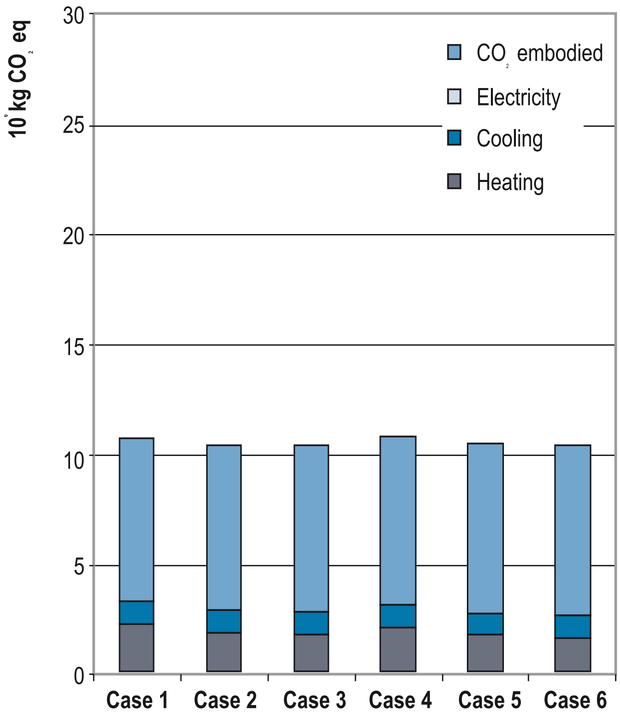

Figure 3. The share of each energy consumption and embodied CO_2 equivalent in different cases when district heating, cooling from bio-fuels is used and electricity is from renewable energy sources.

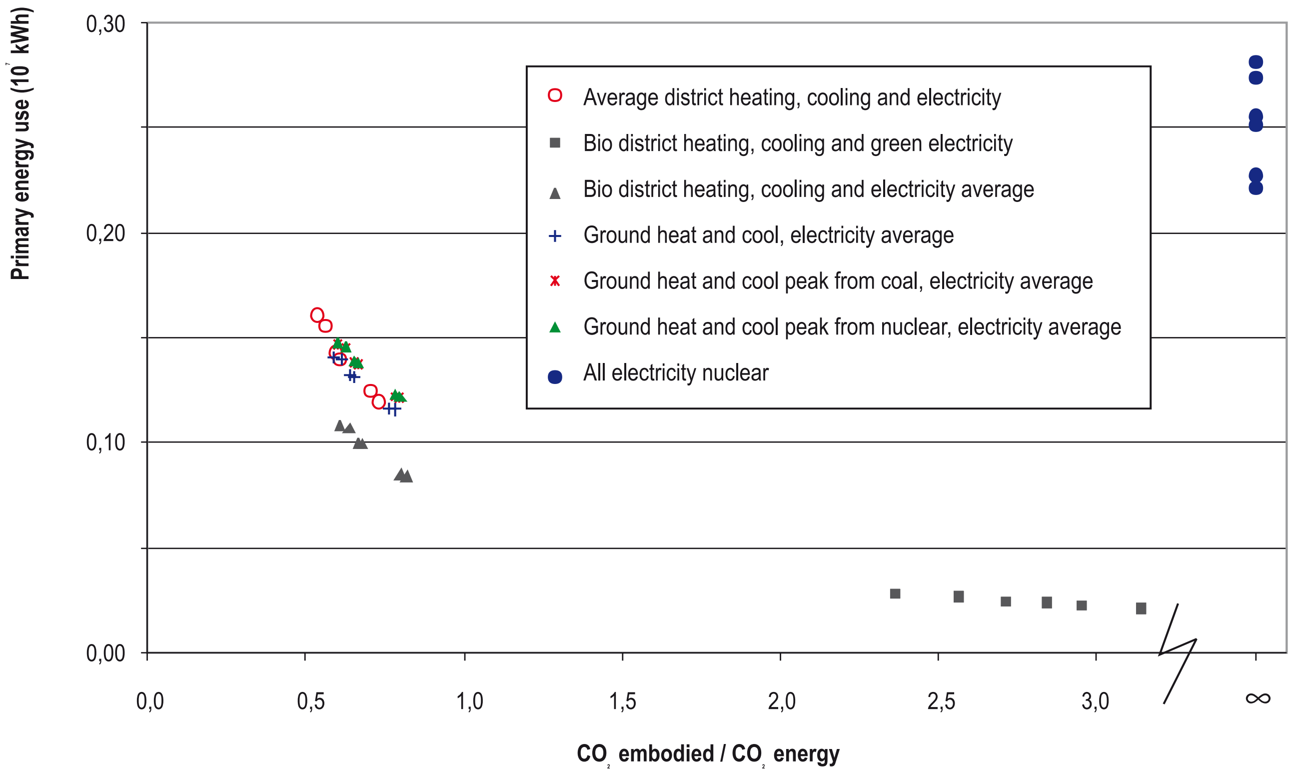

Figure 4. Primary energy consumption as a function of the relation between embodied and energy derivated CO_2 equivalent emissions.

they can utilize the "free" thermal energy obtained from the ground. It can be seen that the local variations do have an effect on both primary energy use and $CO_{2\ eq}$ emission; in some parts the average Finnish values do have a good correlation to local energy production, but in some places the local production is closer to biomass-based production and in other locations closer to peak conditions. The lowest primary energy use is in alternatives based on bio local heating, cooling and green electricity. The lowest relation between $CO_{2\ eq}$ embodied and $CO_{2\ eq}$ energy in addition to low primary energy use was with the cases based on bio local heating, cooling and average electricity. When average electricity or nuclear energy based electricity was used, there was a clear trend in that energy saving gave the highest primary energy use savings.

Discussion and Conclusions

The reduction of energy use reduces both the primary energy use and CO_2 emissions. The reduction of electricity use has a high importance for both primary energy use and CO_2 emissions when fossil fuels are used. Often energy originated from fossil fuels is also used as a complimentary source of energy, thus the importance of reducing energy use and especially electricity originated from fossil sources has a high priority.

The lowest $CO_{2\ eq}$ equivalent emissions were achieved when bio-based, renewable energies or nuclear power was used to supply energy for the office building. Evidently then the share of $CO_{2\ eq}$ emissions from embodied energy from building materials and products became the dominant source for CO_2. The lowest primary energy was achieved when bio-based local heating or renewable energies were used in addition to local cooling. Obviously the highest primary energy was when nuclear power was used. When the primary energy use and $CO_{2\ eq}$ are minimized the $CO_{2\ eq}$ originated from materials become rather dominant. In this study the $CO_{2\ eq}$ emissions originated from building materials and products is between 2.4 to 3.1 higher compared to $CO_{2\ eq}$ emissions originated from building energy use during running time.

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