Identification of environmental impact of office buildings by building element and material groups

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Summary
This study compares materials used in three office buildings with the aim of determining those building elements and materials impacting the environment the most. The study found, that three office buildings had approximately the same amount of environmental impact, with the heaviest building elements, e.g. the structural frame, having the greatest impact. However, some light elements such as internal surfaces and HVAC services also impacted the environment considerably. Two materials, namely reinforced concrete and steel, had the greatest impact on the environment. In addition the maintenance phase was found to contribute significantly to the overall environmental impact of the buildings.

1. Introduction
Many studies have reported that the use of building materials can have a major effect on the environment during the life cycle of a building. Together with the operational energy, the material-use is typically the most significant environmental aspect of a building. In some studies the materials can lead to as much as one-quarter to one half of a building’s environment impact [1], [2]. Individual building materials are typically distributed over a wide range of elements in a building, and thus the number and amount of building materials is influenced by the design solution of each building element. Especially in Finland, the element-based classification is widely used in the design and specification of buildings [3]. Traditionally, the environmental effects of a building’s structures have been dealt with according to the building materials used [4], [5]. Only a few studies have analysed the environmental impact on the basis of both building elements and materials, and in those cases where it has been done only one or two impact indicators were considered [6], [7]. The purpose of this study is to determine the environmental impact caused by both building elements and materials used in three office buildings, indicating the most significant ones.

2. Method
A life cycle assessment (LCA) framework was chosen to analyse the environmental effects of three office buildings. The study consisted of three main phases: 1) inventory analyses for collecting the data; 2) impact assessment for evaluating the environmental impact, vis-à-vis each of the three buildings; and finally, 3) data quality assessment for evaluating the quality of the data used. The functional unit of the LCA was the materials used per gross floor area of an office building during the construction and fifty years of maintenance.

The identification and quantification of material flows of the buildings were performed in the inventory analyses. The inventory included the manufacture and maintenance of the building materials. The site-works, operation and end-of-life life cycle phases were not included in this study. The building materials were determined by building elements according to the Finnish building classification system Talo90 [3], and were derived from the drawings and specifications of the buildings. The elements included were the foundations, structural frame, external envelope, roof, internal complementaries, internal surfaces, elevators, mechanical and electrical services. The
service life of the different building elements were estimated according to Finnish guidelines [8]. The emission data of identified materials were mainly collected from the actual building product producers in Finland. The age of the emission data was typically less than 5 years old, and it had been verified by an independent third party organization. The quality of the data used was evaluated using a six-dimensional estimation framework recommended by the Nordic Guidelines on Life Cycle Assessment and was set at the second highest level (number 2 of five) in the framework [9].

In the impact assessment, the impact of each of the buildings was evaluated and compared to the others both by building elements and by building materials. The impact categories studied were chosen according to those designated by the Finnish Environmental Institute and calculated by Kel-Eco software [10], [11]. The impact categories were climate change, acidification, eutrophication and dispersal of harmful substances, which included summer smog and heavy metals. From the original list, ozone layer depletion and biodiversity loss were excluded due to lack of emission data.

3. Presenting the cases

All the three case buildings chosen for the study are office buildings in Southern Finland. The buildings are owned, designed, constructed and operated by different organizations and they have been constructed between the years 1998 and 2001. The case buildings were chosen based on the interest of the owners and the amount of the data available.

Case A is a new high-end office building and occupied by administrative employees. The building has 24,000 m² of gross floor area, and a volume of 110,000 m³. The building consists of a single office tower with nine floors and it has a prefabricated reinforced concrete framework with prestressed slabs. The exterior wall has a double glass facade system. The inner facade is made of painted concrete sandwiches or mineral wool insulated steel panels. The building has two major partition wall types, one made of calcium-silicate bricks, and the other of gypsum board with glue-laminated studs and mineral wool sounding board. Almost 130 different building elements and fifty different building materials were identified in the inventory phase.

Case B is also a new high-end office building [2]. The users of the building are medium-sized high-tech organizations. The building has 15,600 m² of gross floor area, and a volume of 61,700 m³. The building consists of three 5-story office towers. The structural frame is made of in situ cast concrete. The most common exterior wall structure is a masonry wall made of clay bricks having a steel-profile support and mineral wool insulation. The building has two major partition wall types, one made of calcium-silicate bricks, and the other of particleboard with glue-laminated studs and mineral wool sounding board. More than 120 different building elements consisting of over fifty different building materials were identified in the inventory.

Case C is a new intermediate office building [12]. The users of the building are medium-sized public and private organizations. The building has 4,400 m² of gross floor area, and a volume of 17,300 m³. The building has one office tower with four floors. The structural frame is a beam-and-column system with pre-fabricated concrete elements. The exterior wall is made of concrete sandwich-panels, and the partition walls of gypsum board with steel-profile studding and mineral wool sounding boards. More than fifty different building elements and fifty material groups were identified in the inventory phase.

![Figure 1. Comparing the environmental impact of the materials used in three office buildings.](image)
4. Result

4.1 Environmental impact of the three office building case studies

Figure 1 shows a comparison of the three office buildings with regard to environmental impact. As we can see, all three buildings have relatively equal environmental impact. No single building stands out as having the highest or lowest overall impact, with the order of magnitude of the buildings varying between the studied impact categories. The greatest difference between the buildings can be found in the summer smog and heavy metals categories. In the summer smog category, the difference between the highest and lowest values, cases A and C, is eighteen percentage units and it is mainly due to the emissions caused by the paints in the buildings. Case A has more painted surfaces and a higher proportion of solvent-borne paints than case C, both of which impact the environment by causing summer smog. In the heavy metals category, the difference between the highest and lowest value, case A and B, is seventeen percentage units, which is mainly due to the non-ferrous metals used in the HVAC services of the buildings.

![Figure 2. Environmental impact of the three office buildings by building elements.](image-url)
4.2 Environmental impact of the three office buildings by building elements

Figure 2 shows the environmental impact of the case buildings by building elements. The structural frame dominates the result, but also other building elements contribute significantly in individual impact categories. As a whole, the impact data seem to correlate somewhat with the weight of the building elements. In the climate change and eutrophication categories, the correlation seems clear, as is the case to some extent in the acidification and heavy metals categories. Summer smog appears to correlate more with the proportion of metals and paints in the elements rather than to their weight.
The elements of the three case buildings act relatively similarly; the same element group has roughly the same environmental impact. One exception is that of the roof elements, where case A scores lower values, and cases C and B higher. The higher scores of C and B are mainly caused by the use of different insulation (light aggregate vs. polystyrene) and the amount of steel in the roof structures (load bearing beams, waterproofing, machine roofs, etc.). The result varies also in the category of HVAC elements. The HVAC system of case B has significantly less environmental impact than both of the other cases. This is mainly due to the use of centralized building services (e.g. a district cooling system instead of one that is building specific).

4.3 Environmental impact of the three office buildings by building materials

Table 4 shows the environmental impact of the three case buildings by building materials. In most of the material groups the buildings have nearly as much environmental impact. However, the result is dominated by two groups, reinforced concrete and steel. They are responsible for 40 to 80 % of all environmental impact. The reinforced concrete is mainly used in structural elements; the steel can be found in all element groups. In addition, some other materials are emphasized in individual impact categories, for example, insulation in the acidification, paints in the summer smog, and non-ferrous metals in the heavy metals environmental impact categories.

4.4 Environmental impact of maintenance

Figure 4 shows the environmental impact of building materials during fifty years of maintenance. As we can see from the picture, the maintenance phase significantly increases the environmental impact of the buildings. Maintenance also increases the difference between the buildings. The growth of impact can be seen clearly especially in the summer smog category, where the original level of environmental impact doubles or triples in the maintenance phase. This is mainly due to the combined effect of short repair period (8 to 12 years) and the amount of painted surfaces in each case building.

4.5 Data Quality Assessment

The result of the data quality assessment is presented in table 1. As we can see from the table, the data quality indicators score two or less, as targeted in most cases. Sometimes the indicators score over two, but in those cases the corresponding building material has typically a minor influence on the overall result. The only material group that scores more than two and plays a major role in the result is that of paints. Paints score three for all the case buildings and with three different quality indicators. The effect of the lower data quality of paints is concentrated on the summer smog impact, which is primarily caused by paints and steel. The influence is especially strong in the maintenance phase, where frequent repainting multiplies the effect.
5. Discussion

The purpose of the study was to compare the environmental impact of the materials used in the construction and maintenance of three office buildings with the aim of determining those building elements and materials impacting the environment the most. The study found, that all the buildings had a relatively equal impact on the environment with the heaviest element group, namely the structural frame, causing the most environmental impact. However, some quite light elements such as internal surfaces and HVAC services also impacted the environment considerably. Two material groups, namely reinforced concrete and steel, had the greatest impact on the environment. In addition, the maintenance phase was found to contribute significantly to the overall result.

Earlier studies have reported results similar to that found here. For example the heaviest building elements are often reported to cause most of the emissions leading to climate change [1], [5], [7]. Additionally, the order of magnitude of emissions is at the same level in those studies, with the impact of summer smog apparently a subject to a higher alteration.

It was somewhat surprising that three individual office buildings, different owners, budgets, designers, constructor and users notwithstanding, were found to cause rather equal levels of environmental impact. It would suggest that current building design practices lead to construction solutions that impact the environment at comparable levels. The heaviest building elements could perhaps be expected to cause most of the environmental impact, but surprisingly some very light elements such as internal surfaces and HVAC (1% of total weight) could also cause a significant amount of environmental impact (10-30% of total). It seems that the use of some materials such as paints, copper, aluminum, and different type of insulations in building elements can have a considerable effect on the amount of environmental impact they cause.

Some subjective choices were made in the study that could affect the result. For example, no assumption regarding recycling was made for any of the building materials after use. This is contrary to some recommendations and could significantly affect the overall impact of some materials. Many important environmental impact categories, such as ozone depletion, which could affect the final result, could not be covered, and with only three building cases studied it is fair to say that the subject sample was too small to come to any reasonable generalizations. Finally, in the future it would be interesting to compare the environmental impact of other kind office buildings, especially those with unconventional design solutions.

6. References