THE ADOPTION OF LCA TO ASSESS SUSTAINABLE BUILDING TECHNOLOGIES IN OFFICE BUILDINGS

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Summary

The intention of this paper is to support the adoption of Life Cycle Assessment (LCA) environmental tool to assess sustainable technologies in office buildings. Existing research on LCA has been applied to assess the impact of building materials, building components and building services from cradle-to-grave; nevertheless there is less focus on the use of sustainable technology in buildings and its contribution to reduce energy demands and potential costs in the long run and this is somewhat surprising as energy is mainly consumed during the use stage of buildings for heating, cooling, ventilation, lighting and for other appliances.

According to current research, the environmental design of office buildings holds a particular interest, as a matter of fact, at the moment, a large proportion of all companies with a certified environmental management system are already operating. Some clear indications of the importance attached to office buildings are already appearing. Several studies in office buildings have also shown that energy consumption for space and water heating is higher than that of lighting and for the use of other electrical (60%).

Consequently, this paper supports the adoption of LCA to assess the impact of sustainable and conventional technologies on office buildings in order to make better choice between conventional and sustainable products. Finally, the paper will emphasize that with the use of Life Cycle Assessment we can ensure that we take the right decision from the early stages of the building product processes in order technologies to become environmental friendly, durable and to last for long time.

Keywords: life cycle assessment, sustainability, heating systems, energy consumption

1 Introduction

The term sustainability has been widely used for the past few years. Since 1987 it has been internationally recognized by “the World Commission Report on Environment and Development and manifested by the United Nation Environmental Programme, the Earth Summit at Rio ,the Kyoto Protocol, the Earth Summit at Johannesburg, the Malmo

Declaration"; however even if opportunities exist to reassess this situation both from the government and the private sector, such as "the adoption of national sustainable development strategies, frameworks of international and national environmental law and technological innovation with new resource-efficient technologies", sustainability is still difficult to implement[1].

In fact, some of the sustainable targets raised from the above summits have not been met. Recently, the COP15, also known as the United Nations Framework Convention on Climate Change, which took place in Copenhagen(December 2009), aimed to "stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system". Climate scientists estimate that the world must cut its emissions by 80% by 2050 to limit global warming to a 2°C average rise [2].

Generally, the aim of all the protocols and agreements has been to minimize green house gas emissions. Several statistics and surveys have shown that nowadays, the building construction sector uses higher amount of energy compared to transportation and industrial sector which is not surprising if we thing about how many existing buildings have been abandoned and demolished and how many new buildings are built each day and how energy in buildings is operated.

The building sector has a range of impacts on the environment through the high consumption of resources; around 30-40% of all raw materials consumed in the UK and other developed economies are used in buildings, leading to related energy and pollution impacts. Also, buildings use 16% of global water withdrawals and 25% of annual global wood harvest is used for construction and during the 20th century, chemically based and treated materials became widespread in the buildings industry, affecting the health of people, flora and fauna [3].

In the UK each year, 260 million tones of mineral are extracted and 72 million tones of construction and demolition waste is generated from building projects. The property and construction sectors account for a very large proportion of resource use and environmental damage [4].

In Switzerland, annually, the construction sector is responsible for approximately the consumption of 75 millions of tons of material, of which the greatest part is virgin material. Every day, 11 hectares of arable land disappear. This means approximately 1.3 square meters each second. Around two thirds of this land, especially on the plateau, becomes housing and infrastructure areas. Nationally, around 15'000 new housing buildings rise every year. Of them, approximately 75% are single occupancy and 25% apartment houses. Roughly, 500 new service buildings are also built in this lapse of time [5].

Furthermore, buildings generate emissions and diminish landfilling capacities. In 2002 for instance, housing accounted for the consumption of 28% of energy exploited in Switzerland.

Heating and production of hot water in residential housing are responsible for about 60% of the total Swiss combustible consumption, i.e. fuel oil and natural gas. In addition, 32% of the total Swiss electricity utilization is generally utilized by this sector [5].

In the UK, heating fuel is the most important component (57% of domestic consumption, 52% of non-residential building consumption). Water heating accounts for 25% of domestic consumption and 9% of non-residential use. Lighting accounts for up to 25% of emissions due to commercial buildings [6].

Buildings can also impact the environment because of the emissions they contain, for instance ozone depletion consists of chlorofluorocarbon compounds which reacts with sunlight and create chlorine which destroys ozone. CFCs are used in a number of building components, including some form of insulation, air conditioning, refrigeration plant and firefighting systems as wells as some packaging foams, aerosols sprays and soft furnishing [7].

According to the United Nations Environment Program, buildings are responsible for more than one third of total energy use and associated greenhouse gas emissions in society, both in developed and developing countries. Furthermore, according to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), "under a low-growth scenario, building-related CO_2 emissions and energy use, could increase from 8.6 billion tones in 2004 to 11.4 billion tones in 2030 and under a high-growth scenario, it could increase to 15.6 billion by 2030" [8].

On the other hand, the Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report based on the results of over 80 surveys worldwide, has concluded that "there is a global potential to reduce approximately 29 percent of the projected baseline emissions from residential and commercial buildings by 2020 and 31percent from the projected baseline by 2030 at a net negative cost" [8].

In the US, energy use in buildings, accounts about 40 percent of GHG emissions. The largest source of GHG emissions is used by commercial buildings. Most of this energy is produced by burning fossil fuels, such as coal, natural gas or petroleum, which release CO_2. In the EU 160 million buildings use over 40% of Europe's energy and create over 40% of its carbon dioxide emissions, and that proportion is increasing [9].

Scientists and other government bodies, have been trying to create integrated methods, standardized frameworks and polices that can be understood in the same way internationally but until recently, there has been little concern about the methods and approaches being used to achieve environmental balance by changing the ways that buildings are designed to perform. There are some sustainable tools, where each serves its own specific purpose; however there is small focus on how to investigate how buildings impact the environment. Solutions like renewable energy technologies exist for existing and new buildings but such solutions cannot guarantee that a building is sustainable. In order to ensure sustainability a life cycle holistic approach is needed.

2 Life cycle assessment (LCA) review

LCA's definition and framework has been internationally standardized from ISO 14040 (1996-2000), although LCA has been used by thousands of companies across a range of sectors to guide product and process improvements in different ways. Thus, LCA has been defined as a scalable concept where you can choose how detailed and precise you want to be [10].

The main aim of LCA is to examine the full life cycle of a product, from raw material extraction and acquisition, to material production and manufacturing, use, end of life treatment to final disposal. Through this methodological approach, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided [11].

According to ISO 14040(2006), LCA is defined as "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle".

Life cycle assessment is a very significant tool with considerable value as it is the only one which examines the full life cycle of products and gives knowledge about how products and other activities impact the environment. Compared to other tools, it is significant because it studies environmental impacts, it is based on objective data and even thought it has been characterized as a complex method, it identifies and quantifies the environmental loads involved in the energy and raw materials used, and the emissions and wastes consequently released. Also it helps to assess and evaluate the potential environmental impacts of these loads and it provides opportunities for environmental improvements. Furthermore it supports environmental decision making and it contributes with its findings to global problems, such as global warming and toxic emissions.

The aim of Life Cycle Assessment is to assess the environmental aspects and potential impacts associated with a product by assembling an inventory of relevant inputs and outputs of a system, evaluating the potential environmental impacts associated with those inputs and outputs and interpreting the results of the inventory and impact assessment phases in relation to the objectives of the study. These key ideas have been divided in four methodology steps, shown in the following table.

Tab. 1 Life Cycle Assessment Framework

LCA Standardised Framework (ISO 14040)			
Goal and Scope Definition	**Inventory Analysis**	**Impact Assessment**	**Interpretation**
Life cycle definition	Data collection	Categories	Reconsider Assumptions made on the study
Functional unit	Refine system boundaries	Classification	
		Characterization	
System boundaries	Flow chart and Calculations	Weighting	

3 LCA in the built environment

LCA has currently started to be used in long lasting products such as in building materials which account for a very large proportion of resource use and environmental damage.

LCA methodology can be applied to the building-construction sector, including building products and building components, from single to a group of buildings, from small to large to assess environmental impacts. However, these products are complicated, as each building is unique with different characteristics. This makes the application of LCA difficult as more data and extensive research is needed.

For instance, the life span of a building cannot really be known, buildings have a specific location which means local impacts will not be considered in the assessment, buildings and their components and products are heterogeneous in their composition. Hence, much data is needed and the associated product manufacturing processes can vary greatly from one site to another.

Also the building life cycle includes phases, such as the construction, use and demolition process which have variable behavior in the environment. Another important difficulty is that buildings are highly multi-functional, which makes it difficult to make decisions on functional units and if buildings are integrated with elements from urban infrastructure, LCA would not be recommended. LCA is still developing and many issues will arise when adapted. However, it is the only environmental tool which aims at finding out which emissions occur in different life cycle processes and how these emissions impact the environment, thus it is still under development and used by many practitioners.

Currently there have been LCA studies, more or less comprehensive which examine the whole building or parts of it, to find significant contributors to the environmental profile of buildings and to identify opportunities for improvement, it provides a detailed analysis of LCA results of different building components, on different levels of simplification. The main objective of this study is to simplify LCA and to provide results of similar quality and less effort, as a comprehensive study [12].

Oscar, O. et.al presents a review of different LCA approaches and methodologies (based on international standard series ISO 14040) used to address the environmental and socio-economic aspects of sustainability, from different practitioners, in the past seven years. The intention of this study is to explore and evaluate the different ways of using LCA in building materials and component combinations (BMCC) and of using LCA for the whole process of the construction (WPC). For this study twenty-five case studies have been analyzed, where 60% applied LCA to BMCC and 40% to WPC. This LCA review has also shown that there has been more interest in examining the use phase of the buildings and less focus for the whole life cycle process [13].

Kotaji et.al stated that energy consumed during preconstruction is about 10% to 20%; Adalbert and Bisset stated that operation phase accounts about 40% and 50% and Kotaji concluded that dismantling phase accounts about 1% [13]. The most common environmental impacts to be studied are the global warming, acidification and energy consumption, although there were few studies like that of Peuportier's which addressed successfully all the environmental impacts related to the environment and more specific to the green house effect, including environmental load like photochemical ozone creation, water consumption, depletion abiotic resource, human toxicity, ecotoxicity and others [13].

Another current case study by Viral P. Shah et.al (2007), has applied LCA framework to evaluate three heating and cooling systems which differ in the source of energy and the type of the system. The systems studies are: central natural gas furnace heating and conventional central air-conditioning, natural gas powered hydronic heating and conventional central air-conditioning and electric air-air heat pump for heating as well as cooling[14].

The study's intention is to compare the three systems in terms of their life cycle environmental impacts over a period of 35 years and to assist owners and property developers in decision making at the construction and renovation of a building. The design and performance of these systems depends on the regional climate, so a hypothetical study has been chosen where systems are installed in a new single family residential house, tested in four different climatic locations [14].

Kofoworola, O.F. et.al, also mentions other LCA studies that have been undertaken to develop eco-label criteria for hand floor coverings (Balbo 2002), compare building insulation products (Schmid 2004), asses potential environmental impacts that might result from meeting energy demands in buildings (Osman and Ries 2007) and to assess CO_2 reduction in the construction industry through the selection of materials for houses of low environmental impacts (Abeysundra 2007) [15].

Generally LCAs have focused on building materials, building components, energy, water, waste management and most of them have concentrated in residential than in industrial and commercial buildings, due to limitations on data collection.

4 Office buildings and energy use

"Office building is the most tangible reflection of a profound change in employment patterns that has occurred over the last one hundred years. In present-day America, northern Europe, and Japan, at least 50 percent of the working population is employed in office settings as compared to 5 percent of the population at the beginning of the 20th century" [16]. Since the 20th century, office buildings have increased and the sizes, functions, aesthetics and the structures (raised floors and suspending ceilings) have enormously changed, which proves that there is a need for more and good quality office spaces. But what actually defines good quality nowadays? Some years ago, all it used to matter was the function, the aesthetics, the use and the practicality, but since global warming became an important issue to solve, terms such as energy efficiency and sustainability appeared and became fundamental for every activity in the construction industry. Building performance nowadays has been the main aspect in constructing buildings and it is significant to reduce energy ratings and the green house gas emissions.

Several statistics in the US and the UK have shown that office buildings use the higher amounts of energy compared to other types of buildings. The Commercial Buildings Energy Consumption Survey (CBECS) of the US has also figured out that offices, retail and service buildings use most energy because these types of buildings are very common and there are many of them across the country. Together they account for 39 percent of all commercial floorspace. Most of the energy used in office buildings, is used for electricity, about 66% and about 23% is used for Naturals gas [17].

Ten years ago, office buildings appeared to use about 2,039 trillion Btu of primary electricity, which brings the total energy consumption for office buildings up to 2,383 trillion Btu, or 23 percent of total primary consumption for all commercial buildings. Energy use is distributed among a number of different uses in office buildings. Lighting accounts for the most use, about 29% followed by space heating, about 25% and then from office equipment, cooling and water heating. Further statistics have also shown that commercial building types- office buildings have the highest total expenditures for energy; about $15.8 billion per year is spent for electricity [17].

In the UK, according to the environmental construction handbook and the energy consumption guide (ECON), in terms of operational and embodied energy use, office buildings use higher amounts of embodied energy compared to dwellings, which is the energy used on the extraction of raw materials, on the manufacturing, construction and maintenance of the building and emit high amounts of CO_2, where operational energy used by dwellings, as there is more diversity in lifestyles and activities than there is in business practices[17]. Although, it could be argued that office buildings use more operational energy than dwellings because of the equipments and the building services they use for lighting, cooling, heating and ventilating which can differ according to the size, the function, the type, the orientation of the office building, and the local climate. The ECON19 has mentioned four different types of office buildings in the UK (table2).

Tab. 2 The four different types of office buildings in the UK

Types of office Buildings	**CO_2 Emissions $KgCO_2/m^2/annum$**
1. Naturally ventilated with cellular offices between 100-3000m2. These offices are usually smaller, technologically straightforward; they use daylight with simple control systems for artificial lighting and with limited common spaces and catering areas.	56.8 typical 32.2 lowest quartile
2. Naturally ventilated with some cellular offices and conference rooms, between 500-4000m^2. This office type is characterized by open plan, higher light levels, use of office equipments and vending machines and usually artificial lighting is switched on in wide areas.	72.9 typical 43.1 lowest quartile
3. Air-conditioned standard office type, usually built for speculative reasons, with deeper floor areas, between 2000-8000m^2.	151.3 typical 85.0 lowest quartile
4. Prestigious air-conditioned, are built for a purpose and can be as head or regional offices, with staff restaurants, centre computer suite, extensive IT capability with wide range of equipments, between 4000-20.000m^2.	226.1 typical 143.4 lowest quartile

Source: The Government's Energy Efficiency Best Practice programme [17].

The prestigious headquarter offices for instance, consume up to 600 w/m^2. A good practice where well-proven energy efficient features are management practices have been used, consumes about 400w/m2 and a typical office type, like the natural ventilated, consumes about 150-250w/m^2 [19].

According to the above figures (table 2), energy consumption increases rapidly in all the office types, however, the prestigious offices use additional energy because occupants tend to have longer working hours and more service areas like kitchen and restaurant. Furthermore, the air-conditioned types use extra electricity to run fans, pumps and controls for their handling systems as well as for lightings, office equipments, telecommunications and lifts. Consequently, the electricity on air-conditioned offices accounts between 80%-90% of the total energy and CO_2. The performance of the mechanical systems though, depends on few factors such as orientation of the building, form of the plan, detailed design of eternal envelope and on internal heat gains generated within the building[19].

In terms of costing, in UK, fuels from gas or oil account typically £1.80/m2 in all the office types. Based on the annual costs showing benchmarks for different office types, [18], it can been said that good practices use half or less than a half energy, where most of it is spent for electricity in air-conditioned offices which is about 80%-90% of the total energy costs and CO_2.

5 LCA analysis in office buildings

The LCA review study of Oscar Ortiz [13] has shown that most current LCA studies have focused on residential buildings rather than commercial and this is because it is believed that there is not enough information to complete LCA in whole office buildings.

One of the first life cycle studies in office buildings, was in 1998, an estimation of life cycle energy consumption and CO_2 emission of office buildings in Japan by Michiya Suzuki. Until that time there was no quantitative analysis for environmental emissions, so the United Nations Framework Convention on Climate Change suggested the need to develop a simplified method. The aim of the Suzuki's study was to quantify the total amount of energy consumption and CO_2 emissions caused by the construction, operation, maintenance and renovation of office buildings in Japan. In order to do that, it was suggested to estimate first the total quantity of domestic products and services used directly or indirectly during the life cycle stages of the building. For this purpose a set of input/output tables have been used where the industries in Japan were classified in 400 groups [20].

One of the most notable and influential LCA studies was that of Junilla's who examined the construction of an office of 24.000m^2. About 130 different building parts and fifty different building material groups were identified in the inventory phase. The calculations for the energy consumption for the building were done by HVAC and electrical design using the WinEtana energy simulation program. The environmental impacts that were examined were: climate change, acidification, eutrophication, summer smog and heavy metals [21]. Some of the most current LCA studies in office buildings are mentioned in table 3.

Tab. 3 Current LCA studies in office buildings

Aspects	**LCA Study Analysis in Office Buildings**		
Reference	**1. Kofoworola et al.** (2008)[15]	**2. Xing et al.** (2008) [22]	**3. Junilla et al.** (2006)[23]
WLCA			*
PLCA	*	*	
Study	LCA of a typical commercial office building for 50 years service	LCIA on steel and concrete construction office buildings for 50 years service	LCA in newly constructed office buildings in Europe and the United States for 50 years service
Structure	concrete	Steel-constructed with glass walls and concrete-constructed whose east and south walls are glass and west and north are aerated concrete constructed	US/EUR Steel reinforced concrete structure
Gross floor area	60.000m^2	34.620 m^2 and 46. 240 m^2	US/EUR 4.400m^2
Storeys	38	-	US:5 EUR:4
Place	Thailand	Shanghai in China	EUR: Finland, US: Midwest Region
Inputs	Materials, energy	Energy, resources	Materials, energy

Investigated Environmental Emissions-Impacts	global warming, acidification, photo-oxidant	Green house emissions and pollution urban emissions	(emissions studiedCO_2, SO_2, NO_X, $PM_{10)}$
Life cycle phases to be examined	material production, construction, occupation, maintenance, demolition and disposal phases	building materials production, use, end-of-life phase (each phase includes producing, transportation, distributing)	production through construction, use, maintenance, end-of life treatment, transportation in all phases

Abbreviations: WLCA (Whole Life Cycle Analysis), PLCA (Product Life Cycle Analysis)

In the case of Thailand (table 3(1)), office building stock was chosen because it had the largest share of commercial building stock in Thailand and consumed the largest share of electricity in the commercial sector about 43.5%. All offices in Thailand have similar characteristics. The impact categories that have been evaluated are the global warming, acidification and the photo-oxidant, which were important and relevant to the geographical location from an environmental and political point of view. The study assessed the structure and the envelope of the building and excluded the potential of renewable energy use (on site electricity generation with photovoltaic or solar hot water), which would be interesting to assess but maybe in a separate study, indoor air quality during the operation phase, water consumption, water effluents and future technological break-troughs. The results showed that steel and concrete are the most important materials in terms of quantity and impacts on the environment in the manufacturing and operational phases, related to fossil fuel combustion for electricity production [15].

Similarly, in the case of the US and European LCA studies on newly constructed office buildings, attention is given to the use phase of the building as well to the embedded materials as the maintenance phase throughout a 50 year period of time. Frequently office building become obsolescent and reconstruction is needed which require high amounts of energy for new materials [23].

This study highlights that previous LCA studies have focused more on the use phase of the building and the operational energy while significant studies have shown that considerable amount of embodied energy (the energy used to extract, manufacture and construct building materials, components or services) has also been consumed. The main focus of most LCAs has been on building materials and more specific on comparing concrete and steel structures and building components (walls, floors, windows). Also LCA studies in office building have been used more in European countries and less in USA. Thus this study compares two office buildings, one in Europe in Finland and one in the Midwest region of the USA [23].

Furthermore a holistic approach has been used, where 53 different building element and 23 different building materials have been examined. The holistic LCA study includes the following phases and processes which can be considered for future LCA studies [23].

Tab. 4 A Holistic LCA approach

Life Cycle Phases	**Processes to be assessed**
Construction	transportation of materials from the supplier to the job site, from the use of construction equipment on the site
Use phase	heating, cooling, lighting, electricity use per year: 184 kwh/m^2
Maintenance	materials, equipments, transportation during the assumed 50 year service life
End of life	demolition of the building and transport to the demolished materials to a landfill

In the case of the study from Shanghai in China (table 3(2)), were the energy consumption from building is rising year after year. Steel and concrete structures are commonly used but it is difficult to chose which on is more environmental friendly, even if steel-construction is saving water under dry construction conditions, is making less noise and dust and destroys less land resources. It produces less solid rubbish and it is recyclable. However it has been found that the life cycle energy consumption of building materials per area in steel-framed buildings is 24.9% compared to concrete-framed buildings. The same appears in the use phase [22].

Summarizing the above information from the three LCA studies, significant considerations are unfolded for the next LCA studies in office buildings. When comparing office buildings, they must have similar characteristics in terms of scale and volume and to be located in places with the same or similar temperatures. Usually a 50 year service time is given for functional unit, where often energy and materials are the only inputs and in most times, building materials and components are assessed. Although in all cases, the use phase of the building appears to consume higher amounts of energy compared to the other life cycle phases. Therefore attention is needed on the operational energy systems and on the technology that is used to provide heating, cooling, ventilation and lighting in office buildings.

6 The adoption of LCA to assess sustainability

Current studies have focused on the energy efficiency of buildings by suggesting sustainable technology systems. Some of these systems are accompanied with energy efficient rating certificates but it is still difficult to assess sustainability on products, systems and services and to make a decision on which product is more sustainable than other products.

The following studies show academic sustainable decisions made and methodologies used to improve the efficiency of the building envelope. These studies have also been used in this paper to get a better understanding of how sustainable building technology is used to operate energy efficiently. Furthermore the following studies will unfold considerations for sustainable decisions.

Tab. 5 Academic studies for sustainable building envelope

Facade Type	**1.** Smart Facade	**2.** Multiple Skin Facades	**3.** Photovoltaic and Conventional Facades
Author	Kaluarachchi, Y. et al 2005[24]	Saelens, D. et al 2008[25]	Yun, G.Y. et al 2009[26]
Aim of Study	Discuss issues of facade refurbishment in the UK for multi-occupancy buildings (housing, commercial offices, education, hotels)	To optimize energy performance of multiple-skin facades by changing the settings of the facades and HVAC system according to the net energy of the building	Investigation of the impacts of urban settings on the energy and environmental performances of office space with a conventional and two photovoltaic integrated facade alternatives
Methodology	Comparisons between traditionally glazed facade-double skin-climatic envelopes	The annual energy performance is analyzed for typical Belgian climatic conditions using a whole building simulation tool.	PV electrical and thermal models are integrated into an existing energy simulation tool the LT model to calculate hourly PV electricity production and thermal performance of PV
Suggestions for Improvements	Suggest innovative Technology for low U-value facade with high degree of air tightness	Heating and cooling can be improved by implementing strategies like controlling the airflow rate and the recovery of air returning of the multiple-skin facade	Appropriateness of Urban PV facade in relation to obstruction in Oslo, Cambridge, Milan Efficient facade with optimal glazing ratio

According to the first study (table 5 (1)), to improve the performance of existing buildings, it is required to develop innovative solutions, products and processes, associated with the repairs, maintenance and the use of the building, which can be acceptable among the stakeholders through implementation of strategies. Facades are seen as a protective skin to the indoor environment; waterproof, vapor transmitting, self-repairing. A smart building's skin must have the ability to modify environmental flows through the building envelope by "regulation, enhancement, attenuation, rejection or entrapment". Facades should aim to protect against negative outside weather conditions (wind, rain, humidity), to support the interior room climate, protect against outside energy conditions (heat, cold, UV light), protect against environmental pollutants(noise, exhaust air) and its structure to be durable against temperature, vibration and pressure[24].

This study has identified three facade types, classified considering the construction type and ventilation parameters. Single-skin facades give natural ventilation through the windows and have a standard conventional structure which can be energy inefficient. In order the interior environment to maintain heat or cooling, requires operation of mechanical ventilation systems, with heat exchangers or heat. Sustainability can be achieved with glazing refurbishment and with additional insulation, cladding or with complete refurbishment [24] which is what it would have been decided in most cases for energy conservation. Although the point is to see beyond these standard conservation solutions and assess how environmental friendly they are.

Older building solid walls have a greater thermal mass as they can retain heat better than modern cavity walls, which can help in regulating the temperatures, keeping them cooler in summer and warmer in winter times. The layout of traditional buildings can be energy efficient because of the low proportion of external walls to cross-walls/party walls but they can also be draughty and leak heat, by 'larger windows sizes and a predominance of sash and case windows which provide a greater area of low-efficiency glazing and more potential for draughts'. Some of the old buildings were built before building standards without insulation. Older heating systems use also more energy and generate less heat [27].

This explains why double-skin model facades and climatic envelopes presented in the study 1 are of particular interest for emerging solar and daylighting control technologies such as electrochromic glazing and holographic optical elements [24].

The aim of the study 2 table 5, is to link the building envelope with the buildings performance and to examine naturally and mechanically ventilated single-storey multiples skin facades, by assessing the interaction between airflow in facades and HVAC systems as well with the building energy management system, analyzing the energy performance using a whole building simulation tool. Optimal control strategies are combined with an overall building analysis necessary to increase the energy efficiency [25].

These strategies are restricted to the settings of the HVAC systems and on the analysis of the parameters like geometry of façade, properties of glazing and of the solar shading device. They have to meet specific measurement equipments and an impact on the construction of the HVAC compared with the energy performance of optimized traditional solutions. For the traditional facades, considerable areas for improvement are the heating and cooling. The optimization strategies for traditional facades include a heat exchanger to decrease the ventilation energy, night-time ventilation and free cooling to temper the cooling demand [25].

Other studies have focused on the implications of urban settings for the design of photovoltaic (PV) and conventional facades (table 5(3)). Sustainable renewable energy systems like PV have the advantage that they do not need to occupy land and they do not replace existing building cladding systems. However the application of PV in cities is a big challenge. Neighborhood buildings form obstructions to the sky and sun, minimizing solar radiation which is the fundamental factor for PV systems [26].

The appropriateness of the PV facades depends on the orientation of the building, the streets and the level of obstruction. In order to analyze the effects of urban form and to identify urban influences, the predictions of a PV electrical model are compared with monitoring data of a south facade. The monitoring data includes hourly electricity generation from PV modules, position of the vents to provide ventilation and weather data like solar radiation on south facing and horizontal surfaces and ambient temperatures[26].

For parametric studies the LT model is used (lighting-thermal), to distinguish passive (exposed to the outside) from non-passive zones (protected from outside conditions) for the calculation of building energy use and to quantify building performance and neighborhood environments.

This study highlights the importance of the glazing ratio of three facade types, a PV single skin (PVSS), a PV double skin (PVDS) and a conventional single skin (ConsSS)

[26]. Glazing ratio is the ratio of window area to total wall area for a given facade for the whole building. As the glazing ratio goes up from 10% to 90% the PV output reduces [26].

Summarizing the information provided from the above studies, the following table lists design elements to be considered to achieve energy efficiency.

Tab. 6 Consideration of design elements to minimize energy consumption

Design Elements	Considerations
Siting and Climate	External climate can have a great effect on the interior temperatures which will require more energy use.
Form of the Building (The size of the surface area and volume)	The two factors are directly proportional to the fabric and ventilation heat loss rates. Form dictates the ability with which natural energy can be collected and used like solar, heat, light and natural ventilation.
Building Fabric	The building envelope is a critical component of any facility since it protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's foundation, walls, roof, windows, and doors, the envelope controls the flow of energy between the interior and exterior of the building. A well designed envelope allows the building to provide comfort for the occupants and respond efficiently to heating, cooling, ventilating, and natural lighting needs [28].
Solar Gain	Direct solar gain depends on the characteristics of materials and building components and their thermal efficiency U-value (the lower the U-value the greater the thermal efficiency). Solar strikes the material, then it is absorbed and transformed into the heat, stored in the mass of the materials, the materials then heats up progressively by conduction as the heat diffused through it. Heat penetration is higher in materials with high thermal diffusion coefficient which increases with increasing conductivity [29].
Mechanical building services	The operation of the building services to provide heat, cooling and ventilation in interior spaces, depend on the thermal characteristics of the building fabric. Mechanical services use high amounts of energy which comes from burning fossil fuels. Thus nowadays, renewable energy technologies have been suggested and control systems are provided to control the operation of building services.

Design elements are helpful to understand the building performance and to consider before to design a new building, however when it comes to existing building and the measures that have to be taken to reduce energy consumption and emissions on the environment, it is difficult to decide on which sustainable methods would be more appropriate.

If we are about to assess a building in a holistic way, the maintenance-repair phase of the building will also need to be integrated extensively. Once the operation phase of the building has shown the levels of energy and emissions produced from existing building services, before to make decisions on the replaced technologies or on control systems, LCA can be used to assess how sustainable are the solutions to be used in a building. Furthermore, to understand whether a new sustainable building performs better than a conventional, a full life cycle approach is necessary.

The concentration on LCA studies in terms of sustainable technology has been to compare building insulation products [30], to assess fluorescent lighting in existing buildings [31], to evaluate enhanced condenser feature for air-cooled chillers serving air-conditioned in buildings [32] and to assess the importance of bioclimatic design related to the environmental impact of the entire life cycle phase of a building, by comparing bioclimatic options with conventional practices of design [33].

7 Conclusion

It is important to recognize that energy efficiency can be more productive in commercial buildings, due to an overall corporate staff management system which values the employee's comfort.

Most of the LCA studies on office buildings are on building envelope systems (materials and components) and on other internal elements like walls and floors. Even if current LCA studies on office buildings have shown that the operational phase of the building consumes more energy for lighting, heating and ventilating the interior spaces, there is less focus on assessing the available building technology to reduce energy and green house emissions.

Furthermore, since energy efficient regulations appeared, new buildings perform less energy using eco-friendly technologies although, energy saving on existing buildings with poor fabric and services is as great as 40% compared to the whole building sector (10-20%). Consequently existing buildings have a great potential for energy savings.

The maintenance and repair phase of existing buildings has proven to be extremely important as well as this is where decisions are taken for reducing energy consumption and extending the life of the building. Renewable energy technologies are available, however it is difficult to compare products and make a choice between them.

A building can be assessed before and after is constructed. LCA can provide information before to make decisions on building products, systems and services about how sustainable they are.

When assessing products that are to be used in a building, we need to bear in mind that all aspects of a building's design and construction services have an effect on energy consumption. In order to reduce that we have to identify the role the design aspects play in energy performance.

Life Cycle Assessment can be then used to compare products and assess their durability, energy efficiency, emissions on the environment and their life span.

Sustainable technology like double glazing, insulation products, photovoltaic, wind powers and control systems are widely used, but in order to ensure sustainability and make decisions easier, these products can be compared and assessed with LCA.

Equally worthy of notice is the fact than when using the so called "eco-friendly" materials and "sustainable" technologies, extra energy is needed to extract, manufacture, install and operate them as wells as extra energy will also be needed to repair them in the future or to replace them with others and so on and so forth.

Thus, in order to assess sustainability and improve existing sustainable solutions, LCA must be adopted in the sustainable building technology in a holistic way by examining as many materials as possible. A holistic approach will make available

More results about emissions and their impacts to the environment which is what we should be aiming for.

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