BACHELLOR THESIS

FINAL REPORT

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Can we reduce, renew and offset the carbon footprint of the University of Applied Sciences of Mainz Holzstraße building?

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ABSTRACT

The improvement of energy efficiency and environmental performance of buildings is considered a major priority worldwide. New building regulations have an explicit orientation toward low-emission and energy-efficient designs. However, the optimal design of residential buildings should consider multiple, and usually competitive, objectives such as energy consumption optimization, financial costs reduction and decrease of environmetnal impacts. This makes it a challenging multi-objective optimization problem. The aim of this work is to apply well known methods to a building case of study.

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1. Introduction

This chapter introduces the background to the research problem with particular respect to the measures that can be adopted in order to reduce, renew and offset the carbon footprint caused by the construction and normal daily use of the Fachochschule Mainz (University of Applied Sciences of Mainz) Holstrasse building.

The main objective of this research is to find out viable solutions designed to improve the living standards in urban environments, where CO2 concentration levels are higher. With high population densities and economic activity clustering, cities are the focus for CO2 emission reduction and sustainable development (Y. Geng, B. Xue; 2011). The aims of this work are to demonstrate if offsetting the carbon footprint of the building case of study is possible and also to serve as example or inspiration for future studies about reducing and offsetting the carbon produced by the construction industry.

This research will be directly useful for the Holztrasse building of the FH-Mainz, and indirectly useful for other buildings of similar characteristics: buildings of similar use (education, office works, research works), total constructed area, facilities, city's infrastructure, etc.

In pursuing this objectives, the following structure has been followed.

To begin with, it has been necessary to find information about how much carbon emissions are produced directly and indirectly from construction works every year. This data helps to become aware of the impact that construction works have on global human health problems. Secondly, the main measures that have already been adopted by some Governments and relevant worldwide companies have been studied, in order to move this research along the path set out by them. The priority actions drawn by the report *Buildings & Climate Change: A summary for Decision-makers* have been specially taken into account as well. It's important to know this kind of measures as their efficiency can be also analysed and, if convenient, applied to this research or used as inspiration for finding new solutions.

After collecting the previous data, the third step consisted of analysing the different ways in which every building, including the study case Holztrasse building, cause carbon emissions to the atmosphere.

After that in the Literature Review, some targeted and concrete solutions that have been adopted in different industries have been studied as reference and inspiration for this research. This part contains also the explanation of some important ideas and literature that have outlined the research path.

Next step is to find out the carbon contained in the structure of the building case of study, the carbon emitted during its construction and the carbon emitted because of its normal use. In the final part of this calculation has been also included the carbon emitted by transport and by the energy that make possible the daily working of the building.

Once the carbon produced by the building is known, the possible measures to reduce and offset it will be shown and analysed. Finally all these solutions will be presented as a package of remedies to offset the carbon footprint of the building.

1.1 Background

The Department of Energy and Climate Change says it wants existing buildings to be close zero-carbon by 2050, and has proposed a list of voluntary measures. But there are no plans for a compulsory program similar to the one for new homes, disappointing environmentalists and angering some in the construction industry. (*Carbon Plan*, HM Government).

Today, it is widely accepted that human activities are contributing to climate change. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) estimated that between 1970 and 2004, global greenhouse gas emissions due to human activities rose by 70 per cent (IPCC, 2007). While the full implications of climate change are not fully understood, scientific evidence suggests that it is a causal factor in rising sea levels, increased occurrence of severe weather events, food shortages, changing patterns of disease, severe water shortages and the loss of tropical forests. Most experts agree that over the next few decades, the world will undergo potentially dangerous changes in climate, which will have a significant impact on almost every aspect of our environment, economies and societies. (*Buildings and Climate Change;* 2009).

It is estimated that at present, buildings contribute as much as one third of total global greenhouse gas emissions, primarily through the use of fossil fuels during their operational phase. (*Buildings and Climate Change;* 2009).

Most developed countries and many developing countries have already taken steps towards reducing greenhouse emissions from the Building Sector, but these steps have had a limited impact on actual emission levels. (*Buildings and Climate Change*, 2009*).*

Buildings have a relatively long lifeplan, and therefore actions taken in the present will continue to affect their greenhouse gas emissions over the medium-term. (*Buildings and Climate Change;* 2009).

Moving to a low carbon economy offers enormous economic and social benefits and is a necessary precondition for a successful, competitive economy. It will also reduce reliance on imported fossil fuels and increase energy security. The development of new low carbon technologies can stimulate innovation and can provide employment opportunities in new and existing “green industries” (*The Road to Copenhagen*; Building Britain's Future; 2009).

The compensation of the damages can be achieved with different kind of measures. The main measures to achieve this in the construction industry are compensation and substitution. Compensation consists of improving the damaged part of nature by adopting solutions in the same location of the building. An example of compensation could be the use of green roofs to replace the native meadow that existed in the solar of the building. Substitution consists of improving the damaged part of the nature by adopting solutions somewhere far away from the building. An example of substitution could be offsetting carbon by planting new trees in a different country, far away from the building. In both cases, the offset of certain amount of CO2 takes place. (*Methodik de Eingriffsregelung*; H. Kiemstedt, S. Ott, M. Mönnecke; 1996).

The insulation of the building has been regarded as acceptable and no improvements have been planned or designed on it.

1.2 Motivation

Nowadays in the city of Mainz and in most of the cities in the world the offset of the carbon footprint is not a priority and is not being faced enough to stop global warming (*Buildings and Climate Change; UNEP Sustainable Buildings & Climate Initiative*; 2009). During the last decade many different researches have been developed in order to achieve the theoretical knowledge that allow civil engineers to build better, improving the nature global gases balance.

Next step to achieve this global gases balance is to apply this new knowledge to concrete buildings and start offsetting CO2 and its emissions as soon as possible. The motivation of this project is to serve as a real study about how to reduce the carbon emissions in a targeted case and also how to offset the carbon already emitted, demonstrating that it's possible and giving to the University Of Applied Sciences Of Mainz all the necessary data to do it.

Universities around the world have always given the most important steps in the direction of science and human evolution. This research is an opportunity to continue in this way and offers to the University to be one of the first buildings that offset CO2 and achieves low CO2 emissions by adopting relatively low-cost solutions.

1.3 Research Aim and Objectives

Against the background earlier outlined, this research project will be undertaken with the aim of reducing CO2 future emissions, offsetting the CO2 amount already emitted and renewing materials and energy during the whole process and lifetime of the building.

To achieve this aim, the following objectives will be pursued:

Objective #1- Find out the content of carbon in the concrete structure of the building

Objective #2- Calculate the total amount of CO_2 emitted during the construction of the building, as well as the amount of carbon emitted every year for its normal use.

Objective #3- Work on the hypothesis of applying different solutions at the same time, focusing the all the efforts and actions on reducing CO_2 emissions and offsetting the carbon already emitted.

Objective #4- Find and apply solutions that can be adopted without the need of high CO_2 emissions. The objective is to make all the changes with zero emissions during the process.

1.4 Chapter summary

This first chapter has introduced the background of the need of offsetting the carbon produced by construction works and also of reduce the future carbon emissions. The aims and objectives of the research have been stated and the scope and limitations of the research given. The structure of the report has also been explained.

The next chapter will critique the extant literature.

2. Literature review

This chapter presents and critiques the literature in the extant body of knowledge.

2.1 Overview

The first step given in this chapter has been to find solutions that industries different of construction industry have already adopted and that can serve as valid examples and inspiration for civil engineers. Comparing construction works with other kind of industries, could be said that construction is retarded in the fight against global warming and greenhouse gases emissions. (*Buildings and Climate Change;* Sylvie Lemmet; 2009).

One of the most relevant examples can be found on the **Airlines** Industry. Most of the Airlines flying worldwide offer to their clients the chance of offsetting the proportional amount of CO2 produced by every passenger during the flights. This service consist of paying an extra amount to the company with the aim of helping in the investment activities oriented to plant new trees somewhere in the world. These trees are thought to offset the carbon footprint produced by commercial flights. This measure allows every customer to offset the carbon produced by him/her for flying (*The environmental effects of airline carbon emissions taxations in the US*; Christian Hofer, Martin Dresner, Robert Windle; 2009).

The excellence of this solution can be found under the fact that the company the first element that makes efforts on offsetting the necessary carbon produced for its normal working. On the other hand, the company asks for cooperation to the customers to achieve the carbon neutrality. This factor is positive because shows how a company is able to focus its actions on carbon neutrality and at the same time cooperate in the awareness of their customers about the importance of offsetting the carbon footprint. It's necessary to say that there exist a great part of global population that never heard about the carbon neutrality concept, or don't know how important for the human health it really is.

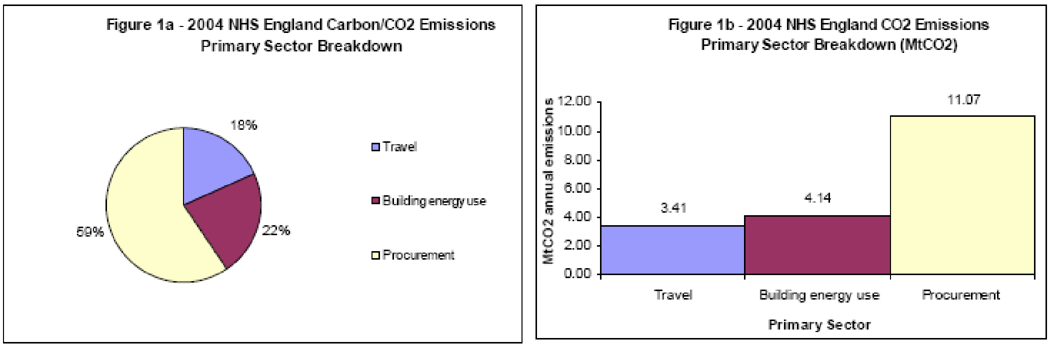
Another factor to take into account is that air substitution effect is considered and it is argued that some air travellers may divert to automobiles, thus increasing automobile carbon emissions. (*The environmental effects of airline carbon emissions taxations in the US*; 2009). In the case of construction industry, this problem would not appear, as the intention is to change the construction habits. Airplanes cannot replace cars, they are different means of transport. However, the solutions for the future ways of construction will replace the pollutant existent.

According to the *Condé Nast Traveller* classification, these are the 10 best airlines in the world: British Airways, British Midland International BMI, Air France, Swiss Air, KLM, Lufthansa, Aer Lingus, SAS, Alitalia and Monarch Airlines. All of them offer to their customer the carbon neutrality service

After an own study, is has been found a direct relation between the good quality service and the carbon neutrality service. This relation *quality-carbon neutrality* can show the line that civil engineers should follow: Quality in construction and carbon neutrality are related. Both of them depend on the priorities of the companies and both of them are though as positive practices.

This literature was inspired by Dr. Professor Andrew Petersen and further developed by the researcher, looking forward adaptation possibilities to the construction activities and building use.

Table 1 –2004 NHS England Carbon/CO_2/GHG emissions: Primary sector breakdown



The example of Airlines is especially useful for civil engineers, as the pollution caused by the both industries (aeronautical and construction) are very similar.

Airlines literature is recent information about services that are being currently offered to every customer. For this reason is understood by the researcher that the path shown by airlines could be followed by constructors and engineers, adapting it in convenience to the buildings. Apart of this, the efficiency of these measures has been already proved.

Other relevant example is the **supermarkets and stores** in Europe and America. Overall in European countries, many companies of this type, such as supermarkets or Malls have followed a common initiative that consists of using renewable energy provided by solar panels on the roof. This is not a new idea, but serves as inspiration the fact that the fight against carbon emissions is shown by these companies as a quality factor. This can mean that carbon neutrality is understood as a positive action that doesn't improve the quality of the products sold by the supermarket, but significantly improves the standards of life of the population. (*Powering the planet: chemical challenges in solar energy utilization*, 2006).

The main difference between the substitution applied by some airlines by planting trees somewhere in order to offset the carbon, the measure adopted by stores can be translated in a reduction of CO_2 emissions. These are two different facts. The first one really improves the air quality in the world or at least is thought to achieve the carbon neutrality. Nevertheless, the second solution doesn´t stop de carbon unbalance, its function is just to reduce the emissions, but they keep on existing and keep on being excessive.

The two examples shown before, airlines and stores, have served usefully to create the final measures for the building case of study, as they follow at least one of the main factors of this research, which are: reduce, renew and offset. These three concepts were citated by some carbon neutrality softwares like *Build Carbon Neutral,* and have become the guidelines for the carbon neutrality. Diverse projects have worked and developed new ideas and solutions by following these concepts.

Other concept that has been important in the development of this research is the idea of ***Design Life***. This concept remarks the importance of working with solutions and measures whose lifetime is the same or near the same than the building in which are working. This has as consequence the need of applying solutions made by good materials and good quality, and planning maintenance for, at least, the first four decades. (*Design Life of Concrete Structures*, 1995)

Experience shows how in many cases different solutions have been used but their durability made the final price much higher than expected *(More than half of Europe's rivers fail ecological targets*, 2012)*.* Design life has been employed in this research to make a special effort on the finding of measures that are viable also in long-term.

The final concept considered in this research is called ***New Ideas*** and is directly related with the amount of money required to carry out a concrete solution.

The last few years were not good ones for those seeking to accelerate the transition to a low-carbon energy system. Ambitious plans to regulate greenhouse gas emissions on a global basis fizzled. Negotiations in Copenhagen in 2009 to frame a successor to the Kyoto Protocol produced a fig-leaf agreement that failed to conceal profound divisions among the major countries. A subsequent climate conference in Cancun accomplished little (*Unlocking energy innovation*; Richard Lester & David Hart; 2012).

To be successful, a broad community of constituents would need to accept the temporal mismatch between immediate costs and long-term benefits. (*Making Buildings Part of the Climate Solution by Pricing Carbon Efficiently*; Marilyn Brown, Matt Coxx, and Xiaojing Sun; 2012).

The last global attempts to reduce the CO2 emissions and achieve the carbon neutrality had in common that required huge amounts of money that companies and countries would “loose” in sunk investments. But the recent experience shows that there was no true willingness and therefore the propositions didn't work. These results changed the direction of the new and future measures, to search new ideas that don't call for huge investments. This is, low-carbon solutions with low-costs.

2.2 Chapter Summary

In short, Literature Review can be collected in a group of four elements of inspiration, two industries – Airlines and Stores - and two abstract concepts – *Design* *life* and *New Ideas* -. All these four elements conform the basis of the solutions adopted and point the way to develop this paper as will be discussed later.

3. Methodology

This chapter describes the Methods adopted and why were they employed to make this paper. In the first part is going to be shown how was calculated the amount of carbon emitted during the different life cycles of the building.

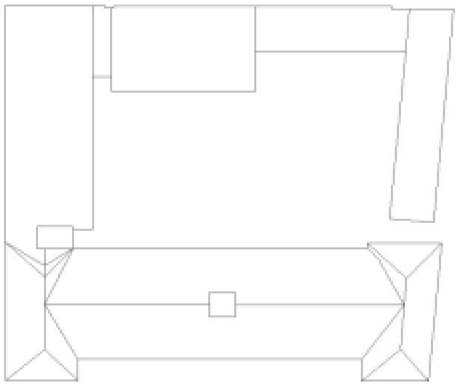
There exists an extreme importance of knowledge in problem solving. If the researcher misses relevant knowledge, an easy problem may appear difficult or impossible (*The Complete Problem Solver*; John R. Hayes; 2009). For this reason, before working on the solutions the Methodology of this research begins with information gathering, such as carbon footprint of the building or its indirect emissions.

3.1 Calculate the Carbon Footprint of the Building

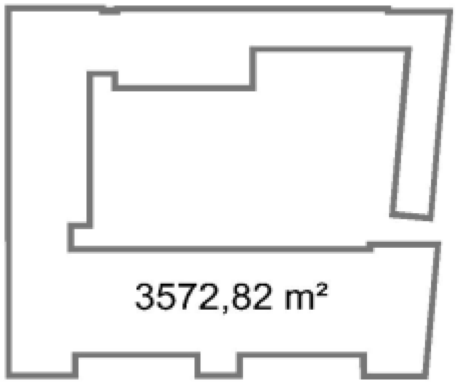
The methodologies for carbon footprint calculations are still involving and it is emerging as an important tool for greenhouse gas management (*Carbon footprint: current methods of estimation*; Divya Pandey, Madhoolika Agrawal, Jai Shanker; 2010). Carbon footprint, being a quantitative expression of GHG emissions from an activity helps in emission management and evaluation of mitigation measures (Carbon Trust; 2007).

The carbon footprint of the building belonging to University of Applied Sciences of Mainz and located at Holzstrasse Street has been calculated by using the software

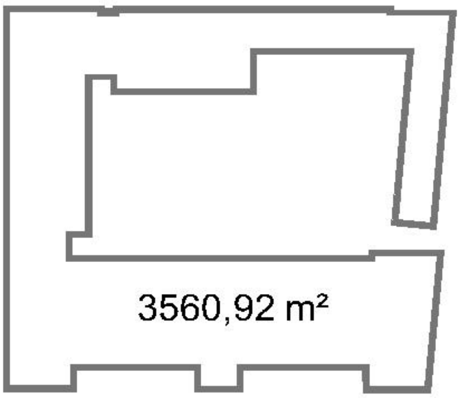
Build Carbon Neutral. This software requires different kind of data, such as the total surface built, stories above grade, stories below grade, system type and information about surrounding vegetation. To find out the total surface built has been necessary to work with the plans of the building, which have been provided by the University. Other tools like *Google Maps* have been as well needed due to the importance of knowing also the outdoor surfaces: parking, garden, etc.; that will play an important role by hosting some of the future solutions adopted against CO2 emissions. Furthermore, the plans had to be drawn newly through the software *AutoCAD*, provided by Autodesk.



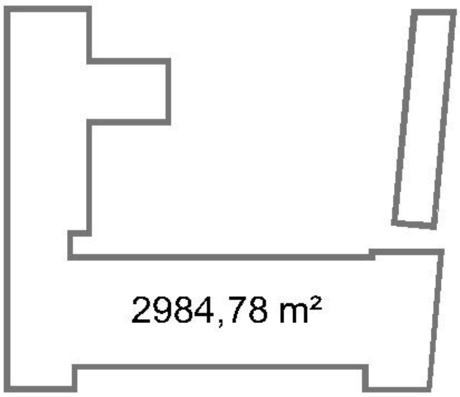
BASIC DESIGN
Top View



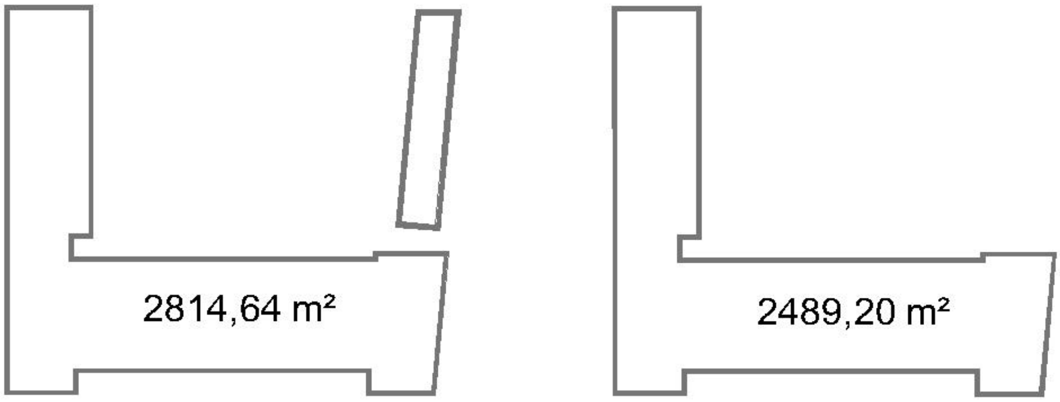
BASEMENT FLOOR



GROUND FLOOR



FIRST FLOOR



SECOND FLOOR **THIRD FLOOR**

The sum of all the built surfaces of the building is 15,422 square meters. As the software used in this case works in square feet, the data introduced have been the equivalent 166,005 square feet. Also the three stories above grade, one below grade, the type of structure (concrete) and the surrounding and native vegetation have been taken into account.

As mentioned earlier, the building has a structure of concrete, with no use of mixed structure or steel structure. (steel has been only employed as reinforcement for the concrete).

Before the building case of study was built, there was in the solar an extension of meadow and some trees (average quantity supposed of 8 trees). This income data has been introduced to the research after observing the surrounding area and its natural vegetation and counting the average amount of trees per square meter (one tree every 514 square meters). The site has 5,132.67 square meters (55,247.69 square feet).

The result of introducing the previous data in the software is the following: the estimated embodied CO_2 of the whole construction project is 7,288 tons of CO_2.

3.2 Find Out the CO2 Produced for the Normal Use

The emissions produced by the building don't stop after its construction. If the building has not been designed in order to reduce the CO2 emissions, use renewable energies and offset the embodied carbon of the structure, the normal use of the building will cause further emissions every year, making the bad problem, even worse.

3.2.1 Daily Transport. Public Transport.

The University Of Applied Sciences Of Mainz provides education by face-to-face teaching. Because of this, the physical presence of students, professors and other stuff are necessary to carry out the normal tasks of an university. This fact carries, in the moment of this research, CO2 emissions caused by public transport and cars every day.

These emissions are directly related to the amount of people that have to move every day from their homes to the classes. Thanks to the information provided by the Secretary and the Students Associations of the University, it's known that there is a total of 1,752 students registered in the Holzstrasse building and it can be estimated that 181 workers perform their duties in this building.

Despite this figures, an own study has shown that every day assist to class 70% of the total of students and workers. This is 1.226 students every day.

This study was made by counting the quantity of people entering to the University during the morning a normal day in the two main entrances. A 20% of the total counting has been added due to the existence of other two gates.

In the same study was proved that public transport is used by 788 of this 1.226 students and workers. The possible variables between the use of bus and train have been supposed after doing a wide study (asking part of the students and adopting the proportions obtained).

The emissions due to public transport have been calculated following the data offered in the *Results of Analysis* of the *Comparison of Energy Use & Emissions from Different Transport Modes*, which is an study made by M.J. Bradley & Associates for the American Bus Association in the May 2007.

MODE	Pass-mi/Gal**			Btu/pass-mi			CO2 g/pass-mi		
	low	**AVG**	high	low	**AVG**	high	low	**AVG**	high
Motor Coach	160.0	**184.4**	201.5	685	**749**	862	51	**56**	64
Van Pool	28.2	**101.9**	194.6	709	**1,354**	4,891	53	**101**	364
Heavy Rail	47.0	**155.3**	200.6	688	**889**	2,939	121	**156**	517
Commuter Rail	58.2	**85.8**	249.1	1,127	**1,608**	2,372	108	**177**	286
Intercity Rail	52.4	**66.0**	175.7	785	**2,091**	2,635	138	**179**	196
Car Pool - 2 person	41.2	**55.4**	111.4	1,239	**2,492**	3,353	92	**185**	250
Light Rail	14.4	**120.5**	214.9	642	**1,146**	9,596	113	**202**	1,689
Trolley Bus	53.4	**104.4**	122.1	1,130	**1,321**	2,582	199	**233**	454
Car - Avg Trip	32.5	**43.8**	88.0	1,569	**3,154**	4,244	117	**235**	316
Domestic Air Travel		**42.3**			**3,260**			**243**	
Transit Bus	3.9	**32.5**	126.8	1,088	**4,245**	35,123	81	**299**	2,615
Car - 1 Person	20.6	**27.7**	55.7	2,478	**4,983**	6,706	184	**371**	499
Ferry Boat	2.0	**12.6**	31.0	4,447	**10,987**	68,632	331	**818**	5,109
Demand Response	1.4	**9.5**	48.4	2,849	**14,562**	99,468	212	**1,063**	7,401

****Passenger miles per Diesel Equivalent gallon**

Determining that the buses (Transit Bus in the table) emit in average 299 CO2 grams per passenger per mile, and taking into account an average movement distance of 4.97 miles (8 km, for going and return):

Passengers · Emissions · Miles = Amount of CO_2 emitted a normal day

492 (passengers) · 299 (CO_2 g) · 4.97 (miles) = **731,126.76 CO_2 g/day**

Determining that the trams (Intercity Rail in the table) emit in average 179 CO_2 grams per passenger per mile, and taking into account an average movement distance of 2 miles:

Passengers · Emissions · Miles = Amount of CO_2 emitted a normal day

215 (passengers) · 179 (CO_2 g) · 2 (miles) = **76,970 CO_2 g/day**

In sum, the CO_2 emissions of Public Transport (bus and tram together) during one day for moving people to the building case of study is 808,096,76 g CO_2, or **808,01 kg CO_2.**

3.2.2 Daily Transport. Cars.

The parking of the University has been designed to accommodate until 29 cars, being the daily use of 25 cars. This can be translated in 40 people moving by car every day.

In Europe cars can be classified in two different types, depending on the fuel needed to work: gasoline cars and diesel cars. Following the information of the German newspaper *Der Spiegel,* in January 2013 50.2% of cars sold in Germany were diesel. So it can be estimated that half of the cars driven in Mainz are diesel and the other half are gasoline.

Taking this data to the parking of the University, it can be considered that 12 cars are gasoline and 13 cars are diesel.

In the calculation of cars emissions, the formulas given by J.L. Sullivan, R.E. Baker, B.A. Boyer, R.H. Hammerle, T.E. Kenney, L. Muniz and T.J. Wallington in their study *CO2 Emission Benefit of Diesel (versus Gasoline) Powered Vehicles*, published in 2004 have been employed. The fuel economy (FE) and fuel consumption (FC) of diesel and gasoline vehicles are related to CO2 emissions by the following expressions:

$$[CO_2]_d = 6231/FE_d = 26.5 * FC_d \qquad (1)$$

$$[CO_2]_g = 5550/FE_g = 23.6 * FC_g \qquad (2)$$

The subscripts d and g denote diesel and gasoline, respectively. The units for the terms in eqs 1 and 2 are as follows: g/km for $[CO_2]$, miles per gallon for FE, and L/100 km for FC. The different constants in eqs 1 and 2 reflect the fact that diesel and gasoline fuels have different densities and carbon contents. The range of gasoline and diesel densities specified for use in North America and Europe are similar; therefore, one set of fuel properties for each fuel was used for all the calculations in this study. (*CO2 Emission Benefit of Diesel (versus Gasoline) Powered Vehicles,* 2004*).*

“Diesel vehicles have higher fuel economy and lower CO2 emissions than their gasoline counterparts” (*CO2 Emission Benefit of Diesel (versus Gasoline) Powered Vehicles,* 2004*).*

Furthermore, the European Union Automotive Fuel Economy Policy, belonging to the United Nation Environmental Program (UNEP), give the data concerning to the cars CO2 emissions. “A decade ago, the European Union entered into a series of voluntary agreements with the associations of automobile manufacturers that sell vehicles in the European market to reduce CO_2 tailpipe emissions. These agreements apply to each manufacturer's new vehicle fleet, and set an industry-wide target of 140 grams CO_2 per kilometre (6 l/100km).” (The European Union Automotive Fuel Economy Policy; 2011).

Based on the previous formulas:

$FC_d = FC_d = 6$ l/100km

$[CO_2]_d = 26.5 \times Fc_d = 26.5 \times 6 = 159$ g/km by diesel cars

$[CO_2]_g = 23{,}6 \times Fc_g = 23.6 \times 6 = 141.6$ g/km by gasoline cars

The average movement distance is 8 km (go and return):

159 (g/km) x 8 (km) x 13 (cars) = 16,536 g/day by diesel cars

141.6 (g/km) x 8 (km) x 12 (cars) = 13,593 g/day by diesel cars

In short:

16.536 (kg) + 13.593 (kg) = 30.13 kg CO_2 per day by cars

Rest of people use a bicycle for moving to the university and back (394) or just walk (262).

3.2.3 Electricity Production

The calculations focused on the CO_2 emissions by the electricity provision for the building begin through finding out the total amount of electricity needed during one year. According to the study *Umwelt schützen und Kosten einsparen* (Protect the environment and save money) wrote by A. Zenger, the building case of study employed in 2002, 608.000 kWh.

On the other hand, the Climate Change Commission of the Government of Catalonia gives in its *Guía Práctica para el Cálculo de Gases de Efecto Invernadero* (Practical Guide for the Calculation of Greenhouse Gases) of 2011 the standard value to calculate CO_2 emissions caused by electricity consumption. This value is 181 g CO_2/kWh. Linking the recollected data:

608,000 (kWh/año) x 181 (g CO_2/kWh) = **110.048.00 g CO_2/year**

3.3 Estimate the reduction of CO2 offsetting

This part is dedicated to calculate the amount of CO_2 that is not converted by the native meadow and nature existing before the construction of the building case of study.

First step in this calculation is to find the total area of the site. By using the plans made previously for surfaces calculations in AutoCAD is possible to get the value of 6,780 m^2.

Every square meter of the native meadow would clean up an average quantity of 1750 g / m^2 / year, if it existed instead of the building. (Table I. Estimated productivity for certain ecosystems; *Fotosíntesis, Productividad y Algas Marinas*; M. Edding, F. Tala, J. Vásquez; 2006).

Ecosistema	Kcal g^{-1} m^{-2}	gC m^{-2} año^{-1}	g m^{-2} año^{-1}
Bosque templado de hojas caducas	5.000		600 – 2500
Selva tropical	15.000	1.300	1.000 – 3.500
Pradera de hierbas	2.000	1.500	2.000 – 1.500
Desierto	500		10 – 250
Pantano costero	12.000		800 – 3.500
Océano cerca de la orilla	2.500		
Océano abierto	800		2 – 400
Arrecifes y praderas de algas			500 – 4.000
Estuarios			200 – 3.500
Plancton zona costera		20 - 40	
Plancton mar abierto		10 – 20	
Laminaria, Canadá		1.300 – 1.900	
Macrocystis, Océano Indico		1.200 – 2.000	
Thalassia, Caribe		600 – 800	
Macrocystis, California		400 – 700	
Spartina, Atlantico USA		100 - 350	
Zostera, Washington		50 – 300	
Zostera, Alaska		30- 1500	

6,780 (m2) x 1,750 (g CO_2/m2/year) = 11,865,000 g CO_2/year = **11,865 t CO_2/year**

3.4 Calculate Emissions after "Bicycles Measure"

With this section begins the part of the calculations oriented to reduction, renewing or offsetting carbon. The reason why bicycles are the first solution analysed is that the use of bicycles was the main idea at the beginning of this research, and also could be the most different, and at the same time viable solution.

The called *Bicycles Measure* (name given by the researcher) consists of adopting the use of the bicycles as the only mode of transport to the building case of study. This is an hypothesis in which every student and every worker moves to the Holzstrasse building by bicycle, without using any other public or private transport.

Bicycles with electric motors are not included in this study.

Bicycles, as product, do not produce any CO2 emissions while are ridden by a person. Nevertheless, there are some facts that are necessary for this use and which produce relevant CO2 emissions to the atmosphere, such as the emissions during the bicycles production, emissions for the construction of the facilities required, emissions for the production of the extra amount of food needed to feed a person after doing exercise and the emissions due to the rapid human breathing during the ride.

3.4.1 Emissions by food production and transport

For estimating these carbon emissions, some average values have been taken:

– Calculations will be made for an average student, man or woman, because most of people in the university are students. According to the data offered in 2009 by the german *Gesundheitsberichterstattung des Bundes* (Federal Health Monitoring System), the average adult aged 20 to under 25 years old weighs 70.7 kg and is 1.75 m tall.

– It's supposed that one half of students are women and the other half men.

– The Federal Health Monitoring System also calculates the average monthly expenditure on food. “In 2008, households in Germany spent an average of Euro 214 per month on food” (*Consumption Expenditure*).

– Finally, the influence of a nutritionist's work has been excluded, so the average student would eat after doing exercise the same kind of food but in higher quantities.

By using the Harris-Benedict principle to calculate the Basal Metabolic Rate (BMR) of the average student, can be obtained an energetic result of 75.000 kcal per month, in other words, 87.16 kWh per month. The Harris-Benedict equations revised by Roza and Shigzal in 1984 and the data offered by Federal Health Monitoring System about average men and women height and weight, have been applied to this study, as shown below::

$$BMR\ (men) = 88.362 + (13.397 \times \text{weight in kg}) + (4.799 \times \text{height in cm}) – (5.677 \times \text{age in years})$$

$$BMR\ (men) = 88.362 + (13.397 \times 78.0) + (4.799 \times 181) – [5.677 \times ((20+25)/2)]$$

$$BMR(men) = 1{,}874.21 \text{ calories}$$

$$BMR\ (women) = 447.593 + (9.247 \times \text{weight in kg}) + (3.098 \times \text{height in cm}) – (4.330 \times \text{age in years})$$

$$BMR\ (women) = 447.593 + (9.247 \times 62.6) + (3.098 \times 168) – (4.330 \times 22.5)$$

$$BMR(women) = 1{,}449.49 \text{ calories}$$

$$BMR\ (\text{average student}) = (1{,}874.21+1{,}449.49)/2 = 1{,}661.99 \text{ calories}$$

Then, the daily calorie requirements of an average student is 1.662 kcal, this is 33.24 kcal per month (estimating that every month are there 20 academic days). This can be also translated in 38.63 kWh per month. As the student spends 214€ on food, this must also be calculated for 20 academic days: 143€.

With this data can be obtained the value of: 143 (€) / 38.63 (kWh) = **3.7 €/kWh**

Other relevant value for the calculations will be the riding speed. An average velocity

of 16 km/hour has been taken. With the previous income data, the following outcome data can be found:

- The distance ridden every month by the average student to go and return from the university is:

  8 (km) x 20 (d) = 160 km/month

- The riding time every month is:

  160 (km) / 16 (km/h) = 10 hours = 600 min

- According to the formula provided by the Spanish association *En plenitud* for the counting of calories in different sports:

  For 16 km/h: 0.049 x (weight x 2.2) x (minutes of practice)

  0.049 x (70.7 x 2.2) x 600 = 4,572.88 Cal/month = 5.32 kWh/month

- The total amount of money spent in food (energy) for riding every month is:

  5.32 (kWh/month) x 3.70 (€/kWh) = 19.68 €/month

Next step in this calculation is focused to find out the emissions produced by the food bought with this 19.68 €. An average shopping list has been employed, for 90 euro, as well as the data provided by L. Aston, J. Smith and J. Powles in a research.

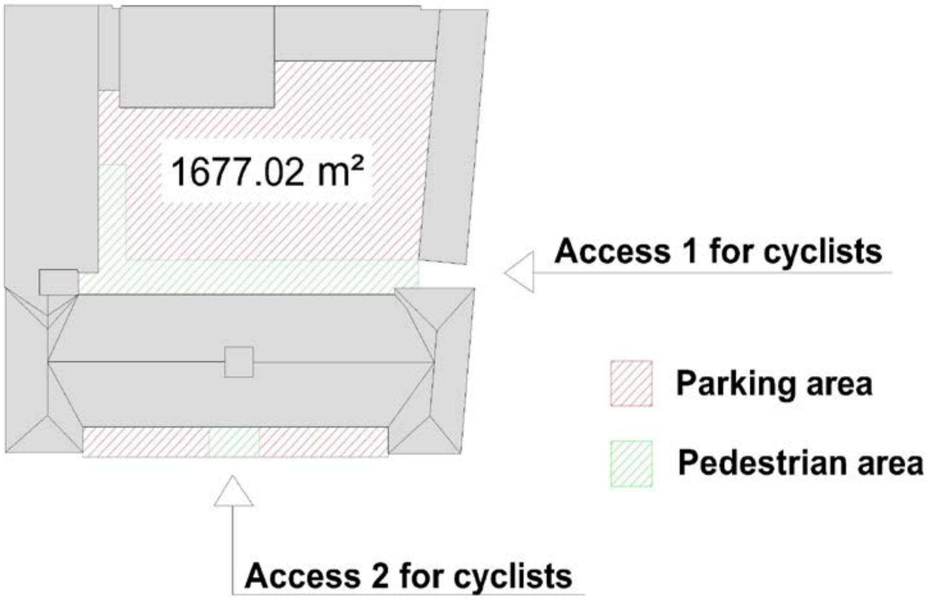
Type of food	Weight (kg)	Price (€)	GHG emissions (kg CO2/kg)	Total GHG emissions
Rice	5	3	1.68	8.40
Pastas	10	6	0.81	8.10
Fruit	10	15	0.40	4.00
Vegetables	5	10	3.30	16.50
Meat	6	25	10	6.00
Bread	2	5	0.73	1.46
Milk	15	15	1.30	19.50
Others	-	11	-	-
TOTAL	53	90		**63.96**

For equivalence relation, if 63.96 kg CO2 are emitted by the production and transport of 53 kg of food valued at 90 €, for the amount of food required to ride the bike during one month is 13.98 kg CO2 produced by the food needed by an average student to have the energy to ride a bike in his/her university displacements (go and return) during one academic month. This quantity will be applied to every student and worker of the university. Multiplying the last figure for ten months shows the emissions during one academic year (2 months are holidays): **139.8 kg CO2/year.**

3.4.2 Facilities Design for the Building

In this hypothesis, it's supposed that all the students and workers of the university move by bicycle. This means that every day would be parked there 1353 bicycles (70% of total students and workers, as they don't must assist to class every academic day).

To achieve this, bicycles must be parked in the existing garden areas and cars parking. A possible distribution is shown below. The space available in the outdoor areas of the university is: 1677.02 m2 in the central garden and 252.53 m2 in the two side yards.



Pedestrian paths are modified, respecting the minimum space required to get in the building with normality. Some entrances would be obsolete in this new design.

Before designing the parking distribution, some basic principles must be assumed:

- All the bicycles must be parked in only one floor
- Every parking place must be always accessible
- It must allow cyclists to pick up and set down their bicycles in every moment

"The rack should consist of a grouping of rack elements. The rack elements may be attached to a single frame or remain single elements mounted within close proximity to each other. The rack elements should not be easily detachable from the rack frame or easily removed from the mounting surface. The rack should be anchored so that it cannot be stolen with the bikes attached -vandal- resistant fasteners can be used to anchor a rack in the ground." (*Bicycle Parking Guidelines*; 2002).

The dimensions of the rack are shown on the graphic below in centimetres. Separation of 75 centimetres between racks and 75 cm with the borders or walls. The path must have be at least 140 cm wide and the racks must have at least 100 centimetres of free longitudinal space, front and rear.

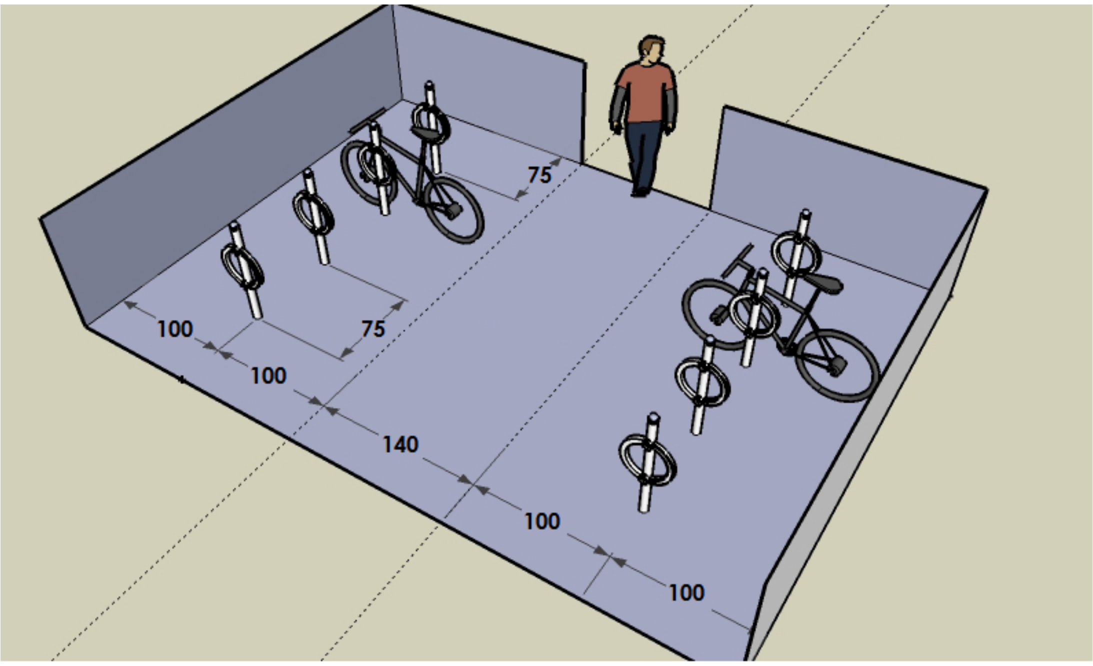
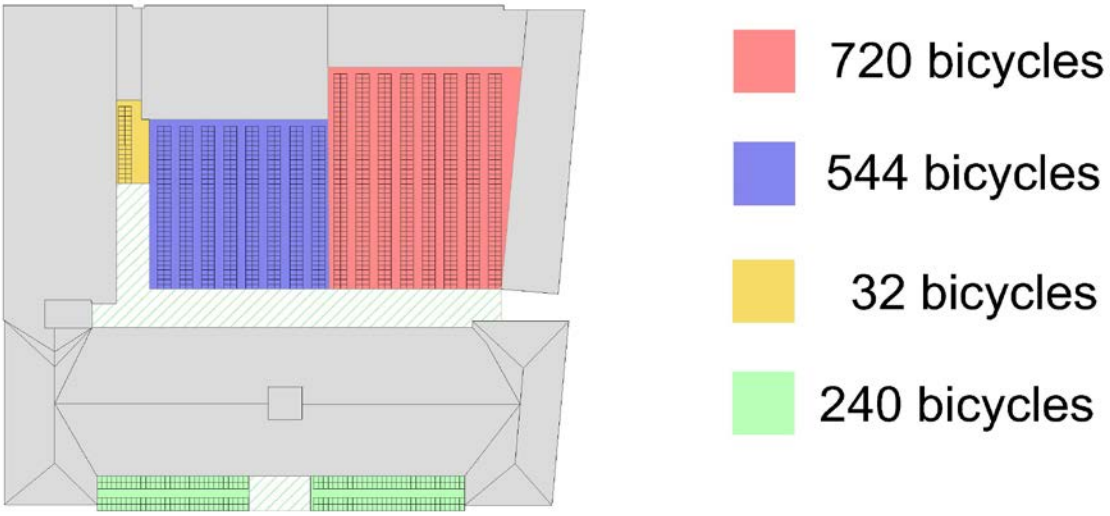


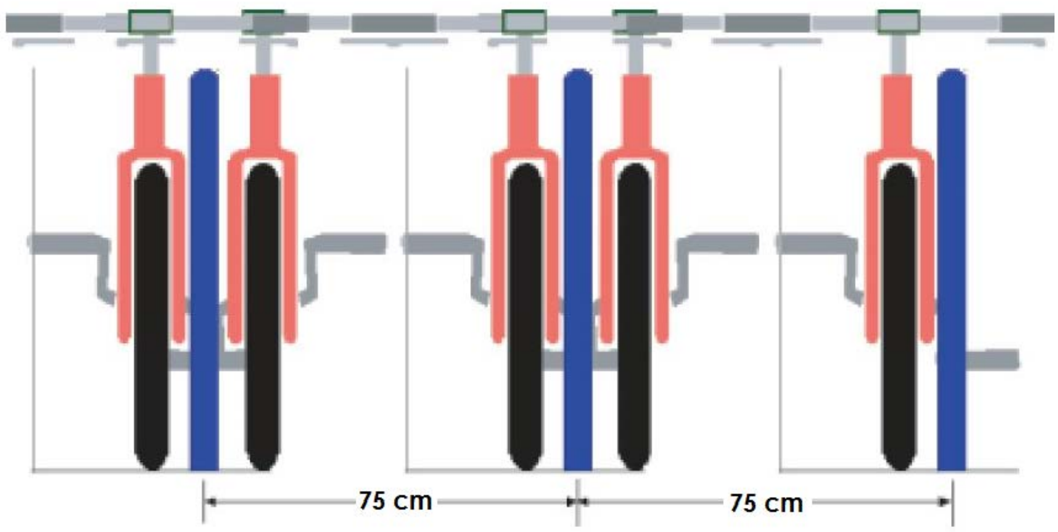
Image modified, taken initially from the *Bicycle Parking Guide* made by City of Cambridge, 2008

The proposed design is able to accommodate until 1,536 bicycles (183 more than



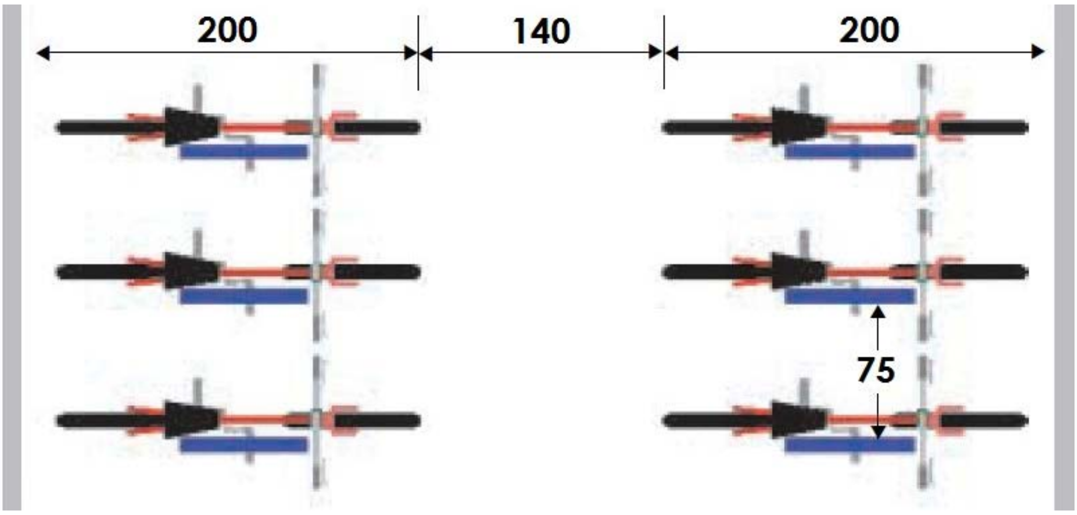
the minimum required). The distribution is as follows:

There will be 8 rack lines of 45 racks each (red area), 8 rack lines of 34 racks each (blue area), one rack line of 16 racks (yellow area) and 4 rack lines of 30 racks each (green area). Every rack is designed to park two bicycles. Detailed views:



Front View. Image modified, taken initially from the *Bicycle Parking Guidelines* made by Association of Pedestrian and Bicycle Professionals, 2002

Side View of the rack. Image modified, taken initially from the *Bicycle Parking Guidelines* made by Association of Pedestrian and Bicycle Professionals, 2002



3.4.3 Emissions by Construction, Facilities and Exhalation

It's tough to say exactly how much greenhouse gas making a bicycle requires, since none of the major manufacturers has release data on their energy consumption. Independent analysis has used a couple of different measures. Shreya Dave, a graduate student at MIT (Massachusetts Institute of Technology), estimated that manufacturing an average bicycle results in the emission of approximately 530 pounds of CO2 (**240.40 kg CO2**). This research concluded also that the use of bicycle involves the average emission of **33 g CO2 per passenger per mile**, taking into account not only the exhaled gases by the cyclist, but also the infrastructures required.

At this point, is known that approximately 1,200 bicycles would be bought for the new transport system for all those people who didn't move to the university in this way. With the previous data, can be calculated that this bicycle production would emit **288,480 kg CO2.**

Likewise, if every cyclist emit 33 g CO2 per mile, the average student would produce for eight kilometres (4.97 miles) 164.01 g CO2, and all the people moving every day to the building case of study , would produce 221,92 kg CO2 per day. This is 4,438.40 kg CO2 per month and **44,380 kg CO2 per year.**

3.5 Calculate Improvements with Renewable Energies

In previous sections have been calculated the amount of carbon emitted by the electricity production for the building case of study, **110.048.00 g CO2/year**.

This emission would stop if the electricity was produced by solar panels that take profit of the sun to produce electricity free of carbon emissions.

However, during the production of the components and modules (aluminium frame, etc.) that are part of the photovoltaic installation (PV), CO2 emissions are unavoidable. Thus, since the whole panel is not only composed by renewable materials, but also components from gas, fuel and coal, this modules and specific components production for PV installations produces CO2 emissions.

Vasilis Fthenakis and Erik Alsema published in 2006 the updated version of the studies about CO2 emissions caused by external reasons. To achieve this, they worked with the data provided by the CrystalClear Project of the European Commission, that was supported by the main companies of the sector in Europe and America.

The emissions were calculated as emissions generated during the whole lifetime of the solar panel. The next table shows the conclusions of interest for this research:

Total CO_2 emissions for 1kW intallation	
Kind of panel	**Emissions in t CO_2**
Polycrystalline silicon	2.06

Every day, the building case of study is using electricity during 14 hours (opening time). So:

14 (hours/day) x (20 days/month) x (10 months/ year) = 2,800 hours/year

608,000 (kWh/year) / 2,800 (hours/year) = 217.14 kW

If the construction and installation of 1 kW of power emits 2.06 tons of CO_2, the construction and installation of 217.14 kW would emit 4**47.31 tons of CO_2.**

The building requires every year the consumption of 608,000 kWh, in other words, the amount of carbon emitted to the atmosphere nowadays is **110 t of CO_2**.

This means that the period need by the solar panels to payback the CO_2 produced during their construction and installation is:

447.31 (t CO_2)/ 110 (t CO_2/year) = **4.07 years**

Can be estimated that, since the fourth year of the normal working of the solar panels, the electricity produced will be 100% carbon free.

3.6 Calculate Consequences of Green Roof and Façades

In order to accelerate the payback and offset process, part of the original meadow will be installed on the top roofs of the building. This means that 4,337.59 m2 of the native 6,780 would clean the air and improve the air quality.

Using again the formula given by M. Edding, F. Tala and J. Vásquez, it's possible to calculate the new CO2 offset values:

4,337.59 (m2) x 1,750 (g CO2m2/year) = 7,590,782.5 gCO2/year = **7.59 t CO2/year**

4. Data Analysis

In this section are going to be supposed the main possibilities to adopt and their respective consequences in emissions and offsetting.

4.1 Bicycles as only way of transport

Here is going to be collected the outcome data calculated before, for finding the results of applying the *Bicycles Measure*.

If the only way of transport to the University were bicycles, all the students and workers would need to eat more in order to replace the energy spent by riding their bikes. The CO_2 emissions caused by this **extra food production and transport** is **139.8 kg CO_2/year.**

Furthermore, the **new 1,200 bicycles** needed for the new cyclists would cause:

240.40 (kg CO_2/bike) x 1,200 (bicycles) = 288,480 kg CO_2 = **288.48 t CO_2**

And following the paper of Shreya Dave newly, counting the average emission per passenger per mile, every year would be produced by bicycles **44.38 t CO_2.**

In view of this, implementing the *bicycles measure* to the Holzstrasse building would mean the approximated emissions of **44.52 t CO_2/year** and a unique emission of **288.48 t CO_2.**

On the other hand, the massive use of bicycles would fully stop the emissions caused by the public transport and cars. **Cars** produce every day 30.13 kg CO_2, and **every year 6.03 t CO_2**. **Public transport** causes 808.01 kg CO_2 during one day, and **161,60 t CO_2 during one year.**

161.60 (t CO_2)+ 6.03 (t CO_2) = 167.63 t CO_2 not emitted every year

In summary, the introduction of the *Bicycle Measure* to the building would need approximately 2 years to payback the carbon emitted for the production of the new bicycles. The first year the emissions would be double than an average year nowadays, because of the huge emissions made by bicycles production. But from the second year, the payback will significantly increase.

First and second years: (288.48 + 44.52) / 167.63 = 1.98 years

Third and further years: emissions of 44.52 t CO2/year

All these results mean a relevant reduction of the CO2 emissions, but in not CO2 offsetting. The carbon footprint of the building does not change**.**

4.2 Apply All Solutions

In this last hypothesis, the three measures are going to be installed at the same time and for a critical analysis of the results.

First, it's important to remind the carbon footprint of the building case os study: **7,288 t CO2.** The only way to make a real offset of this carbon footprint is to convert it in oxygen, and to get this, the use of plants (meadow) will be necessary.

The calculated **meadow** will clean up **7.59 t CO2/year,** so it will take 960 years to clean the whole carbon amount embodied, leaving out the crucial emissions caused by bicycles every year. In fact, meadow's effect would only clean the pollution caused by the use of bicycles every year, reducing this emissions from 44.52 t CO2 to 36.93 t CO2. **CONCLUSION: EL MEADOW NO ES SUFICIENTE.**

The impact of the **solar panels** on the emissions would be paid back in 4.07 years. Since then, the use of electricity would be carbon free and, as consequence, it would produce an important reduction of emissions. If all the solutions were applied at the same time, the first year would be the worst regarding to CO2 emissions.

The values of bicycles construction and transport and solar panels construction and installation will increase the carbon emissions. But after five six years of normal working of the building, all the extra emissions would be totally back paid and the annual values would considerably improve.

5. Conclusions and Recommendations

In conclusion, it's possible to reduce the carbon emissions by the massive use of bicycles, the installation of green roofs and solar panels. This last measure would, moreover, make use a renewable energy (the sun) leaving out the electricity produced with CO_2 emissions. The use of bicycles has been proved as viable with the parking design and calculation.

However, the only concept that is not possible to meet is the concept of *offsetting* the carbon already produced, due to the characteristics of the building. To achieve a real offsetting, it would be adequate to make use of replacement measures. Planting huge amounts of trees in different parts of the world would indirectly offset the carbon embodied in the building.

After the first years of pay back, the Holzstrasse building would still produce positive CO_2 emissions. The meadow area on the top roofs is not enough to clean even the CO_2 emitted by the bicycles.

As many researchers comment, the global situation is not encouraging, regarding to the greenhouse gases emissions. For this reason, although the three measures presented don't offset the carbon, they can be considered as three good options to actively participate against the global warming.

A good part of the emissions that would take place for adopting the “green measures” would not be necessary if the building had been planned with carbon neutrality thinking. In other words, the presented solutions and other are viable not only for this case, but also for future buildings (adapting dimensions and other facts).

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