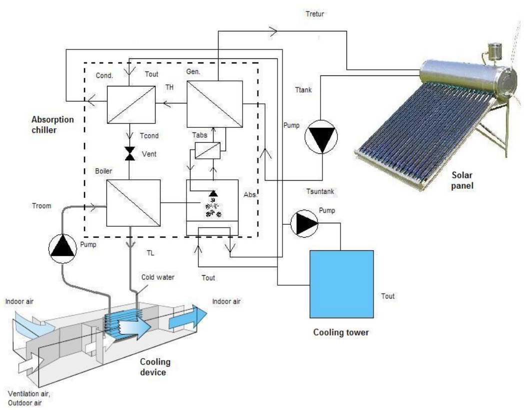
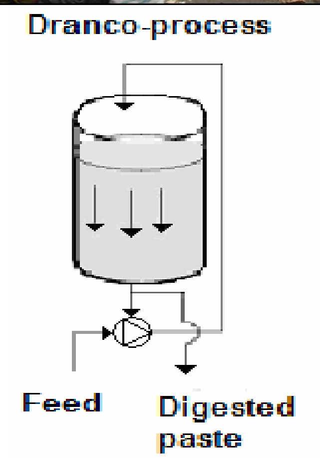
Master Thesis March 2007

Sustainable Energy Use in Tropical Urban Housing

Minor Field Study on Potential Use of Biogas and Solar Powered Air-Conditioning in Guayaquil, Ecuador





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Preface

This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida /Asdi.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in a Third World country. The results of the work are presented in an MFS report which is also the student's Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. The overall goals are to widen the Swedish human resources cadre for engagement in international development cooperation as well as to promote scientific exchange between unversities, research institutes and similar authorities as well as NGOs in developing countries and in Sweden.

The International Office at KTH, the Royal Institute of Technology, Stockholm, administers the MFS Programme for the faculties of engineering and natural sciences in Sweden.

Sigrun Santesson
Programme Officer
MFS Programme

Foreword

This was a study with the aim of investigating possibilities of implementing environmentally sustainable energy solutions in a tropical urban low-income area. The knowledge and social information about the proposed area was poor before the field study was executed. To be able to make preparations and a preliminary literature study before the field study was conducted three points of investigation were set together with the department of Housing Development and Management and with background information from previous visits in South America. The aim was that the three points should support an environmentally sustainable development and an economical and indoor comfort improvement for the low-income families.

One of the points of investigation was to study weather it was possible to implement small scale biogas plants that could supply the households with cooking gas. This would fit the aims of the study by supplying free gas, being more environmentally friendly than the presently used Liquefied Petroleum Gas (LPG) and it could even facilitate the garbage collection which often is a problem in poor areas. It was however found impossible for many reasons after only conducting a small part of the field study. Most importantly because of the large present consumption of LPG compared to the small amount of produced organic waste.

Another point of investigation was to study whether it was possible to substitute electrically heated warm water with warm water from solar panels. The problem was that there was hardly any need for heated showering water in the warm climate of Guayaquil. Very few houses had hot water which meant that there would have been no environmental gain of implementing hot water from solar panels. These things led to that only one of the points of investigation remained intact and the method, purpose and aim of the investigation had to be changed.

Acknowledgements

The authors would like to thank all the personal at IPUR, but especially architect Ana Solano the director of IPUR and architect Ivette Arroyo. Ana Solano for up letting her house and her great hospitality and Ivette Arroyo for her help and guidance.

The authors would also like to thank Fundación Huancavilca for their support and help in realizing this study. Special thanks to Mr. Jimmy Villareal and Mr. Alexander Díaz and all the participants of the questionnaire study in Guasmo.

Special thanks to Marika Murto PhD. at Lund University and Mr. Diego Jendretzki at ECONICsystems for their time and expertise in the field of biotechnology and absorption chiller technology.

Finally a great thanks to our supervising professors Erik Johansson PhD. and architect Laura Liuke at HDM Lund University, for good advice and making this study possible.

Abstract

The aim of this thesis was to investigate whether it is possible to reduce the use of fossil fuels in tropical urban households. Two proposals for achieving this; production of biogas and use of solar powered air-conditioners were investigated in the low income area of Guasmo, in the city of Guayaquil, Ecuador. The investigations were conducted by gathering 100 questionnaires for background information. 49 samples of solid organic waste from 10 households were collected to investigate the biogas production potential. Finally theoretical calculations of the cooling effect and simulations of indoor climate were carried out to determine the effectiveness of a proposed solar powered air-conditioning system on a normal house in Guasmo.

The questionnaires showed that 98 % of the households use the fossil fuel liquefied petroleum gas (LPG) for cooking and spend in mean $ 2.7/month on it. If each of the 33 000 households in Guasmo have the measured mean production of organic solid waste of 1.2 kg/family and day and if it was treated in a Dranco biogas plant 7.26 GWh of biogas could be produced annually. This would be sufficient to supply 6.5 % or 2100 of the households in Guasmo with biogas during one year.

The construction of a biogas plant was found to have good prerequisites in the city of Guayaquil and it would give many advantages compared to how waste presently is treated. The lack of economical arguments and source separation system is however a problem if a biogas plant was to be implemented in Guasmo. A Dranco biogas plant with a capacity of 20000 tonnes of organic solid waste/year today has a capital investment cost of about $ 10 million. The minimum price of the biogas if the biogas plant annually was to break even would be $ 0.17/kWh, three times higher than the present unsubsidized LPG price. The payback time would be 26 years if the present unsubsidized LPG price is used, 6 years longer than the economical lifetime. If the present LPG price is used the payback time is longer still. A biogas plant could however be a solution to the malfunctioning LPG subsidy system which costs the government $ 400 million per year. The government could take away the subsidies but let those in low income areas who source separate their waste keep it. This would give incitements for source separation and the subsidies would end up in the right place. The money the government saves could be invested in biogas projects. Because biogas projects lead to sustainable development and CO_2 emission reductions financial aid could also be received through the clean development mechanism of the Kyoto protocol.

The houses in Guasmo were found to have poor climatic design and 90 % of the inhabitants thought that the indoor climate was unsatisfactory during large parts of the year. A standard house in Guasmo was found to be 12*7.5 meters, have one floor and consists of walls of concrete hollow blocks and a roof of corrugated steel sheets. 80 % of the inhabitants wanted to invest in an air conditioner in the future.

The solar powered air conditioner-system investigated in this study consists of a 2 kW absorption chiller from ECONICsystems and a 4 m^2 locally sold solar panel. The cooling effect was found to be best used during daytime. If it was used between 11 a.m. and 7 p.m. it produces 2 kW during October1st - March 31st and 1.4 kW during April 1st - September31st. The cooling effect gave a 4°C lower temperature in a normal Guasmo house during midday. The investigation also showed that the system works 80 % of the desired hours and that the cost is minimum $ 4000, about two times the cost of a traditional air-conditioner during its lifetime.

The absorption chiller technique has great potential in the future but is too expensive and complicated for the inhabitants of Guasmo today. The system also needs more testing. One advantage is that the system will cool more when the need is high because it follows the intensity of the sun. Another advantage is less used electricity, only 150 W, and less cooling applications with freon. The investment cost will be lower in the future and with higher electricity prices it might be a competitive technique.

Resumen

El objetivo de este estudio fue analizar cómo es posible reducir el uso de combustibles derivados del petróleo en el consumo de energía en viviendas tropicales urbanas. La investigación se concentró en dos soluciones: producción de biogás e implementación de un sistema para aire-acondicionado accionado por energía solar. El área de trabajo se ubicó en el barrio de asalariados bajos, Guasmo, en la ciudad de Guayaquil, Ecuador. La investigación fue realizada a través de 105 cuestionarios que resumieron la información de base. La investigación recolectó además datos de 49 pruebas de desperdicios sólidos orgánicos (basura orgánica) producidas por 10 familias en 5 días, con el fin de investigar la potencialidad de la producción y uso de biogás básicamente para la preparación de alimentos. Finalmente se hicieron cálculos teoréticos del efecto de enfriamiento y simulaciones de mejoramientos del clima interior de la vivienda, para determinar la efectividad de la propuesta del sistema de aire-acondicionado solar en una vivienda típica del Guasmo.

Las cuestionarios mostraron que el 98 % de las familias usan como energía para la preparación de alimentos, el combustible, gas liquido petróleo (LPG Liquide Petrol Gas), lo cual significa un gasto promedio al mes de $ 2.7 para cada familia. Si cada una de las 33 000 familias en el Guasmo tiene una producción de desperdicios sólidos orgánicos promedio de 1.2 kg por día y si estos fuese tratado en una planta de biogás de tipo Dranco, se estaría produciendo 7.26 GWh de biogas por año. Esto sería suficiente para proveer por año al 6.5 %, es decir a 2.100 familias con biogás para cocinar.

Se estima que la ciudad de Guayaquil cuenta con las condiciones necesarias para que la construcción de una planta de biogás sea exitosa, y tenga muchos beneficios sostenibles en comparación con la actual forma de manejar los desperdicios orgánicos. Sin embargo, la debilidad en argumentos económicos y la falta de técnica, infraestructura y conocimientos para la clasificación de fuentes de desechos, son condiciones que actualmente dificultan el proyecto de planta de biogas a realizase en el Guasmo. Una planta de biogás de tipo Dranco con un capacidad de 20.000 toneladas de desperdicios orgánicos sólidos por año, tiene hoy en día uno costo aproximado de $ 10 millones. Si se espera que la planta no tenga perdidas económicas, el precio mínimo del biogás deberá ser de $ 0.17/kWh, lo cual es tres veces mayor que el precio actual del LPG sin subsidios. El pago de la planta culminaría después de 26 años, incluyendo el uso del precio sin subsidios del LPG; esto significa 6 años más que la longevidad económica de la planta. Si el precio de hoy de LPG con los subsidios es usado, el pago en tiempo sería aun más lejano. Una planta de biogas podría sin embargo ser una solución al sistema de subsidios de LPG el cual significa un gasto para el gobierno $ 400 miliones cada año. El gobierno podría abolir parte de los subsidios conservarlos solo en por ejemplo los habitantes de bajos salarios, asentamientos humanos precarios y de bajos recursos y/o en areas donde los habitantes clasifiquen desechos buscando posibles fuentes de energía. Esto sería dar incentios para la clasificación de fuentes y dar subsidios a quienes realmente lo necesitan. El dinero que el gobierno ahorra, podría ser invertido en proyectos de energía verde, por ejemplo derivada del biogás ya que estos proyectos guían desarrollos sostenibles y logran reducción del CO_2. El protocolo de Kyoto ofrece facilidades de ayuda financiera en relación a mecanismos “limpios” de desarrollo, que deberían considerarse, en el caso de Guayaquil.

Las viviendas en Guasmo tienen un clima de interior deficiente, el 90 % de los habitantes piensan que la temperatura en la vivienda es poco agradable durante gran parte del año. Una vivienda estándar en Guasmo tiene una superficie de terreno de 90 m², generalmente tiene una sola planta y esta compuesta por paredes de bloques de concreto perforado; el tejado es generalmente de zinc. 80 % de los habitantes respondieron que les gustaría en un futuro, invertir en un sistema de aire acondicionado, para su vivienda.

El sistema de aire acondicionado generado por energía solar y estudiado en esta investigación, está construido por un sistema de refrigeración por absorción: ECONICsystems, con una efectividad de 2 kW y un panel solar ecuatoriano: TechnoSol de 4 m^2. El sistema demostró funcionar mejor en el dia. Cuando es utilizado entre las 11:00 a.m. y las 7:00 p.m.; el sistema puede producir hasta 2 kW entre Octubre 1 - Marzo 31 y hasta 1.4 kW entre Abril 1 – Septiembre 31. El efecto de enfriamiento da una reducción de 4 grados de temperatura en un día promedio y en una vivienda típica de Guasmo. La investigación tambien mostró que el sistema funciona durante el 80 % en las horas deseadas. El costo mínimo del sistema es de alrededor de $ 4000; aproximadamente dos veces más alto que un aire acondicionado tradicional y considerando el tiempo de vida.

La técnica de enfriamiento con energía solar tiene una gran potencia en el futuro, desafortunadamente hoy en día es demasiado costosa y complicada, aún más considerando el grupo meta, la población de Guasmo. El sistema necesita además mayor estudio. Un gran beneficio es que el sistema es más efectivo en el enfriamiento en tanto la temperatura sea mayor ya que sigue la intensidad solar, intensidad que es muy alta en Guayaquil. Otro beneficio es que se requiere de muy poca electricidad, solo 150 W, y el sistema no tiene ningún contenido de freón. Los costos de inversión de estos sistemas serán muy seguramente menores en el futuro, cuando el precio de la electricidad y combustibles orgánicos sea cada más alto; esto permitirá que la tecnología planteada sea competitiva en el mercado.

Abbreviations

AD	- Anaerobic Digestion
OFMSW	- Organic Fraction of Municipal Solid Waste
MSW	- Municipal Solid Waste
TS	- Total Solids
VS	- Volatile Solids
OLR	- Organic Loading Rate
LPG	- Liquefied Petroleum Gas
PSA	- Pressure Swing Adsorption
HDM	- Housing Development and Management
INEC	- Instituto National de Estadísticas y Censos
IPUR	- Instituto de Planificación Urbana y Regional
SIDA	- Swedish International Development Cooperation Agency
MFS	- Minor Field Studies
Sp/Abc-system	- Solar panel/Absorption chiller- system
COP	- Co-efficient of performance, used as the cooling factor
DEROB-LTH	- Dynamic Energy Response of Buildings, LTH

Table of Contents

1 Introduction

1.1 Purpose and Aim

The purpose of this thesis was to make a realistic investigation of whether or not it is possible to produce biogas in a tropical urban low-income area and to in the same area replace the often used fossil gas LPG (Liquefied Petroleum Gas). By realistic an *"in situ"* study was intended which included all important parameters in the biogas production and usage and to see if it is compatible with the current system.

The purpose was also to investigate in the same kind of study whether or not it is possible to cool houses in an tropical urban low-income area with a solar panel/absorption chiller-system which uses no or only little electricity. In this case only the houses were investigated on site and the possible cooling effect and assemblage of the system was investigated theoretically but with the specific area in mind.

1.2 Relevance of Study

An important reason for why this study should be conducted is because of the fact that large use of fossil fuels negatively affects the global climate. This highly actual problem, referred to as global warming is acknowledged by scientists worldwide and the Kyoto Protocol, which recently was enforced, is a good example of the importance of taking global action to mitigate the problem. But the present global commitment to solving this problem is still not enough and all countries have to make a greater contribution if we are to make a difference. Hopefully the result of this investigation will be a contribution to solving the problem of global warming, even though it might be small.

Another reason for why it is important to conduct this study is because the global resources of oil are diminishing and many scientists believe almost all oil resources will have past their peak of production in 2037.[1] The fact that resources of oil are diminishing will lead to a much higher oil price in the future, as much as 3 times higher in 2010.[2] This will have a large impact on the economy of the poor in areas depending on energy from fossil fuels.

Yet another important reason for conducting this study is because Ecuador imports three fourths of its total consumption of LPG which is used for cooking. This gives great opportunity for development of biogas production which could substitute the residential use of LPG and thereby lessening the use of imported non-renewable energy sources and long way transportation of LPG could be reduced if biogas was produced locally instead.

Last but not least a final reason for conducting this study is because houses in low-income urban areas in tropical climates often have great problems with the indoor climate. According to the Givoni bio-climatic diagram the thermal comfort only reaches comfortable during the nights between June and December in these kinds of tropical areas.[3] Therefore it is of great importance for life quality to try to improve indoor climates in low-income houses in tropical areas.

[1] International Energy Agency, 2004
[2] Leeb S., D. Leeb, 2004
[3] Chevez, F., F. Lucca, 2006

1.3 Setting of Study

This project was a student initiative and was a cooperation with the department of HDM (Housing Development and Management) at the University of Lund in Sweden and the department of IPUR (Instituto de Planificación Urbana y Regional) at the Universidad Catolica de Guayaquil in Ecuador. Help was also received from the non-governmental organisation Fundación Huancavilca which is an organisation that aims to develop social life and micro business in Guasmo, Guayaquil, Ecuador. The authors visited IPUR and undertook the study during the period of August 28th to December 4th 2007.

1.4 Method

First a literature study was conducted about such topics as urban climate-sensitive design for the tropics, renewable energy sources and energy use and supply in Ecuador. Then the thesis was divided into three investigations, two practical and one theoretical.

First a questionnaire investigation of the low-income residential area of Guasmo was conducted. Guasmo is a part of the city of Guayaquil, Ecuador's largest city. This was to collect relevant background information on the consumption of LPG and electricity. It was also to collect information on how the inhabitants perceived their indoor climate, if air conditioning devices or hot water was used, and how the houses in the area were built. This information was later used to quantify the amount of biogas that would be needed to satisfy the consumption in Guasmo and also to see what cost the biogas could have to be a financial acceptable alternative. The information was also used to create a computer model of a standard Guasmo house in which the solar panel/absorption chiller-system could be tested. See the chapter *Survey of Guasmo* later for a more in depth account of the method for this part.

The second part of the investigation was also carried out in Guasmo and in this organic material from 10 families was collected for a period of five days. This was done to be able to approximate the amount of organic material that can be collected from the area and what contents it had, but also to see if it was possible to source separate the solid organic waste. The contents and mass of the organic material was thereafter used to select a suitable biogas producing process and to calculate the amount of biogas that can be produced from it. For a more thorough account of the method for this part of the investigation see the method chapter in the passage on *Investigation of Possibilities for Biogas*.

Finally the third part of the investigation was carried out theoretically in Sweden. It was done by first calculating the amount of heat that can be collected in Guayaquil by a solar panel available in Ecuador. Then a cooling effect which can be produced from this amount of heat from an absorption chiller was calculated. Finally a computer model of a standard Guasmo house was created in the computer simulation program DEROB-LTH and the cooling effect was inserted and the indoor temperature was simulated. The simulated indoor temperature with cooling was compared to the indoor temperature with no cooling. For a more detailed description of this method see the method part of the chapter on *Investigation of Solar Powered Air Conditioning*.

1.5 Background

1.5.1 Ecuador

Ecuador is one of the smallest countries in South America. It has got an area of 257 762 km^2 which can be related to Sweden's area of 450 000 km^2. One third of the 13.2 million inhabitants are living in the three biggest cities. The Capital is Quito and the other two major cities are Cuenca and Guayaquil. Guayaquil is the biggest urban area with 2.5 million inhabitants. Ecuador is mostly famous for its wildlife and many tourists travel to Ecuador to enjoy the beautiful nature. Thanks to the climate differences within the country Ecuador has got an outstanding number of different species of both animals and plants. Ecuador is situated on the equator, as the name reveals, which makes the country exposed to the tropical climate as well as the highland climate in the Andes. The official language in the country is Spanish but there are also many Amerindian languages such as Quechua.[4] [5]

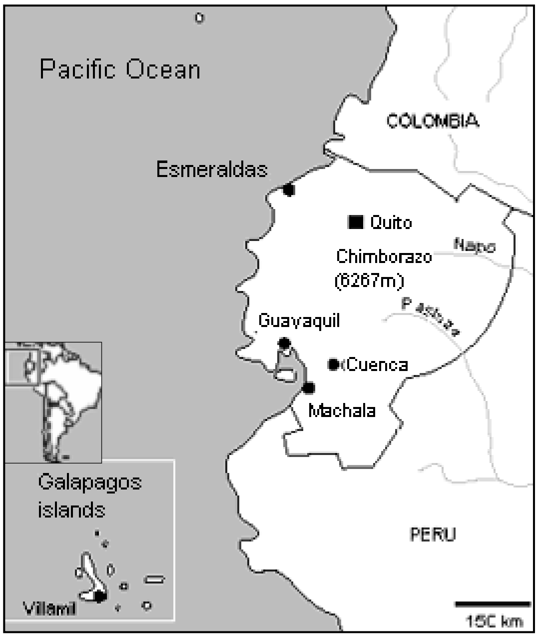

Figure 1. Map over Ecuador and neighbouring countries.

1.5.2 Guayaquil

Guayaquil is situated on the coast in the south west of Ecuador as can be seen in Figure 1. The city is located at sea level, 1.7° north latitude and 79.9° west longitude.[6] [7] Guayaquil and its large harbour export and import more than half of the countries goods. The city has been frequently visited by business travellers but is slowly transforming into a tourist destination. Guayaquil is a strong economical and political centre with many opportunities. Ecuadorians from the countryside travel to the city to look for work and the politicians try to attract people to the city as well to gain political strength.[8] Many however remain unemployed which makes poverty and crime large problems in the city.

[4] Swedish Trade Council, 2005
[5] Finnish Foreign Department, global.finland, 2006
[6] Intervida Ecuador, Aug 2005
[7] Meteonorm 4.0
[8] Arc. Luis Salazar, interview, Guayaquil, 2006-11-17

The city of Guayaquil was founded in 1547 by the Spanish conquistadors. After a few battles with the South Americans the Spaniards placed the first settlements on the east shore of the river Guayas. The city was first named Santiago de Guayaquil, but now only Guayaquil after the indian village that originally occupied the hills of the Peñas. The first houses were also built on the Peñas and the city has now grown along the river Guayas north and south.[9] As can be seen in Figure 2 the city is divided in 32 city regions among which 17 are planned and the rest are spontaneous settlements.[10]

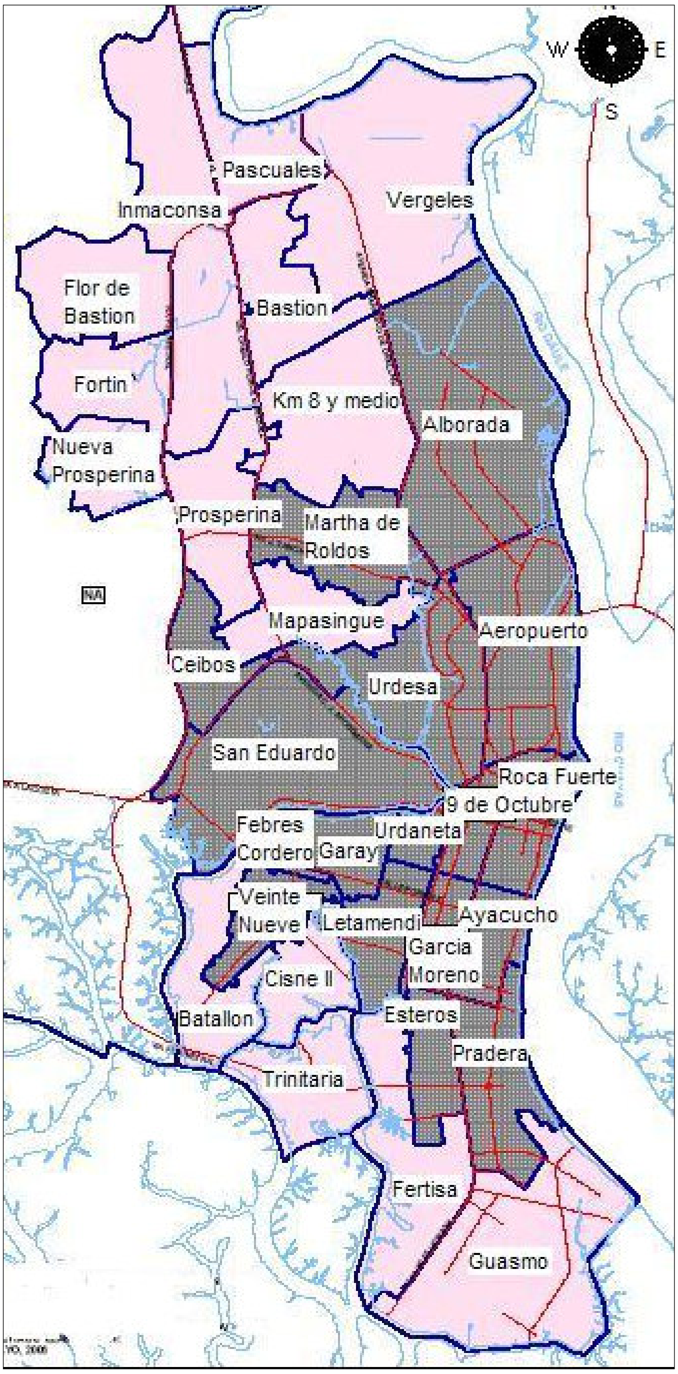

Figure 2. Map over different regions in Guayaquil.

The area around the city gives great opportunities for farming due to the rich and fertile soil and many fruits and crops are cultivated there and sold in the city or exported. A large source of income for the people and the city is the fishing industry that fish shrimps, crabs and fish. A high percentage of inhabitants of the city are working in the fishing industry.[11]

The climate in Guayaquil is warm and humid and because of "El Niño" it has two well defined seasons. The warm current "El Niño" brings warm and humid air from the north to the city between December and May. This period is called winter due to the high precipitation. The mean temperature oscillates between 23.6°C and 31.6°C with a humidity of 80 % and peaks close to 100 %. During the months of June to the beginning of December the city climate is affected by the cold current known as "the Humboldt". The cold sea current from the south means a dryer and fresher weather with temperatures between 20.7°C and 29.5°C and the humidity is 5 % lower in general. This is called the summer season. The temperature has small daily variations all year round. The variation is less than 9°C.[12]

[9] City Tourism Bureau, 2006
[10] Dase, Dirección de Deción Social, 2001
[11] City Tourism Bureau, 2006
[12] Patricio Riviero Murillo, 1999

There are two events that have changed the city of Guayaquil. The first is the natural influence. Even though Guayaquil was founded in 1547 there are very few old houses. This is due to earthquakes and fires, especially "The great fire" that broke out in 1896. The fire ruined large parts of the city and many religious monuments. According to the city guide the fire was so intense that it even melted the gutter in the streets.[13] It is not to wonder that the city was sensitive to fire when most of the houses were built in wood. In the old architecture of the city wood and traditional tools of climate design were used.[12] This changed after the fire. When the city was rebuilt in the beginning of the 20:th century, the "modernity" arrived and designers followed the orthogonal Spanish layout. This meant concrete houses with poor climate design.[14]

The second thing is the numerous publicly financed projects that have recently been built or are under construction in Guayaquil at the moment. The city is undergoing the biggest beautification process ever made in South America. The process was started by the president Leon Fabres Cordeo in 1992 and aims to make Guayaquil to a tourist friendly city. Examples are the construction of the central square and the rebuilt pier, Malecon. A few of the recently built projects can be seen in Figure 3.[15]

Figure 3. Newly constructed areas in Guayaquil, at the left an overview over the Malecon 2000, in middle the Rotonda with the statues of Simon Bolivar and St Martin and the picture to the right is an overview from the Santa Ana over the city and the famous stairs, Las Peñas.[16]

Many cities with poverty problems show architectural contrasts and so does Guayaquil. The central and tourist areas consist of beautiful houses with mechanical cooling and artificial lighting. But 40 % of the population live in the informal sector, slum and squatter areas with low living standards and poor indoor climate.[14]

1.5.3 Guasmo

Guasmo is one of the "new" residential areas in Guayaquil and the people started invading the area only about 35 years ago. The area of Guasmo is populated with 200 000 inhabitants and has an almost even number of men and women, 49.75 % men and 50.25 % women.[17] Guasmo has an area of 1 348 ha and the geographical location can be seen in Figure 2.[18] All the lots and houses in the area are unplanned and illegal invasions. This means that no one in Guasmo own the land where they have their house. This also means that the municipality didn't have any chance to plan the houses to any infrastructure.[19] Most of the homes have got electricity,

[13] City Tourism Bureau, 2006
[14] Arroyo I. A., 2000
[15] City Tourism Bureau, 2006
[16] City Tourism Bureau, 2006
[17] Dase, Dirección de Deción Social, 2001
[18] Intervida Ecuador, Aug 2005
[19] Arc. Luis Salazar, interview, Guayaquil, 2006-11-17

but the percentage varies for different sectors in Guasmo. In the sectors close to the office of Fundación Huancavilca, se chapter 2.1.1, 1.3 % lacked the service of electricity. 90 % of the houses in the same area do have private toilettes but only 55 % of these are connected to a sewer system. Most of the unconnected toilettes have septic tanks. Guayaquil has a common recollection system with garbage trucks that collect the garbage and put it on the landfill in the north-west of the town. The recollection in Guasmo is however poor, 15 % of the households close to the Fundación Huancavilca have to treat their own waste. This is done by combustion, burring or other solutions.[20] The big roads in the area are asphalted but roads in between the houses are still sand or soil. The newly built “Metrovía”, which is a bus system with separate lanes through the city, has the end station in the south part of Guasmo which makes an improvement for communications.

Guasmo comprises of the areas Guasmo central, norte, oeste and sur (north, west and south).[21] Guasmo is one of the poor parts of Guayaquil but not the poorest. The area of Guasmo is not only a young district it has also a young population, 40 % of the inhabitants in Guasmo area younger than 18.[22] Guasmo is situated in the south part of Guayaquil, close to the harbour, the river Guayas and the estuaries. Figure 4 shows a few pictures from the area.

The unemployment in the area of Guasmo is high. According to information from the municipality only 76 400 persons out of 200 000 are working. If children under 18 and the old persons over 65 are assumed not to be working this means that between the ages of 19 and 65 33 % of the inhabitants are unemployed. To run a private company is the most common occupation and according to the information from the municipality 21 % of the working part of the population have their own company and 9 % work in construction.[22]

Figure 4. Three typical pictures from Guasmo. From the left, bamboo houses by the estuary, in the middle one of the main streets and to the right one of the smaller streets.

1.5.4 Financial Situation in Ecuador

During the last decade the economy of Ecuador has been characterized of turbulence and painful economical reforms. To solve the instable situation the government has instituted a number of fiscal reforms that may bring the economy back into balance.[23] One of the latest changes is the dollarization where Ecuador changed their currency from Sucre to the more stable US dollar. Ecuador had a terribly high inflation rate and the change lead to increased stability. Ecuador was very depending on a stable currency as they were going towards an economy based on purchase of imported goods.[24]

The economy of Ecuador has originally been depending on export of raw products like bananas, cacao, coffee and shrimps. Since oil was found in the beginning of the 70’s, Ecuador

[20] INEC, Instituto National de Estadísticas y Censos, Guayaquil, 2001
[21] Arc. Luis Salazar, interview, Guayaquil, 2006-11-17
[22] Dase, Dirección de Deción Social, 2001
[23] EcuadorExplorer, 2005

has been depending on the export of this energy product. This led to an economy highly sensitive to the international oil price and the crisis was a fact in the 80's when the oil market crashed. This sent the country into a vicious circle and the government tried to inflate away its international debt and increase the competitiveness by lower prices on bananas and other raw products. This did not work and the dollarization was the final solution. The macro economy or the countries economy stabilized but left huge problems in the micro economy.[24]

1.5.5 Energy Situation in Ecuador

Total energy use in Ecuador was in 1999 roughly 102 TWh. Divided by sector the energy use consists of mainly three parts as can be seen in Figure 5; transport 38 %, industry 19 % and residential 28 %. There are also three smaller sectors which together contribute with 15 % of the total use. This can be compared to the Swedish use of 406 TWh in 2003 which is a country with almost the same population.[25] Of the total energy use in Ecuador the fossil fuels contribute with about 79 TWh. Renewable energy sources (excluding hydroelectric), consisting of solid biomass primarily and including fuel wood, contribute with 16.3 TWh. Hydroelectric contributes with 6.98 TWh. From this it can be concluded that fossil fuels make out 78 % of the total energy use in the country.[26]

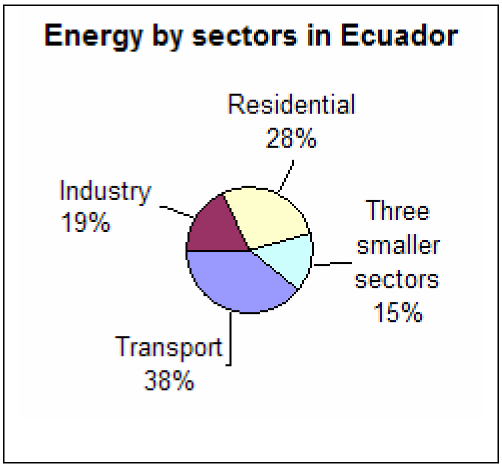

Figure 5. Energy use for every sector in Ecuador.

Electricity use was in Ecuador in 2002 about 11.97 TWh. Of this about 60 % is produced from hydroelectric power plants and 40 % is produced by diesel powered thermal plants. Distribution is poor and suffers from sizable debt loads, which in contribution with the lack of rain during the dry season gives electricity shortages during March-October. During this season Ecuador imports electricity from Colombia. [27]

There are two other important things to notice about the energy situation. The first one is that Ecuador has one of South America's largest consumptions of LPG (liquefied petroleum gas). This is used for residential heating and cooking and domestic production only meets one quarter of the demand and the rest has to be imported.[27] The second thing is that electrical power in the Guayaquil region is supplied by Nobel's Machala facility, which is a 130 MW natural gas-fired power plant situated just south of Guayaquil.[27] This means that all electrical power in the region is supplied by fossil fuel and that the effect of substituting it with electricity produced in a more sustainable way also would reduce the use of non-renewable energy sources and lower emissions of greenhouse gases.

1.5.6 Political Situation

Ecuador is a country that has been under political instability for a long time. The Ecuadorian people have driven the three last elected presidents from their posts. The latest president to be dismissed was Lucio Gutierrez who was replaced by the vice president Alfredo Palacio in

[24] Institute of the Americas, Americas Insights, Arteta Gustavo, 2001
[25] Swedish Energy Agency, STEM, 2004
[26] World resources Institute, Earth Trends: The Environmental Portal, 1999
[27] Energy Information Administration, Official energy statistics from the U.S Government

2005. Close collaboration with the US about natural resources, which according to the people have been sold in an unfavourable way, have been the latest reason for revolution.[28]

A president election was held during the realization of this project. The financial minister under the former president A Palacio, Rafael Correa won the election over the banana tycoon Alvaro Noboa. Rafael Correa is a left wing nationalist with pronounced anti-US stands. Correa has promised to radically reform the country's discredited political system and give back the faith in politics.[28]

[28] CNN.COM, 2006-11-27

2 Survey of Guasmo

To gather background information for the thesis on the residential area of Guasmo a survey study with a questionnaire was performed. The purpose was to investigate how Ecuadorians in a low-income area use energy and what kind of energy luxuries they value. The questionnaire was to provide necessary background information on; how much money is spent on electricity and LPG monthly, if air conditioning and hot water in showers is common, how the houses are constructed and how comfortable the families perceive their houses to be. Information on how the houses are constructed was needed to later be able to make computer simulations of the houses. The information would be used to point out the energy sources that provide the greatest impact on the environment and on household economy. The purpose was also to point out measures that enable a higher living standard for the inhabitants in the area. Examples of these kinds of measures that could be taken are actions to provide a more comfortable indoor climate.

2.1 Method of Survey

A preliminary questionnaire was written in Sweden in Swedish due to poor Spanish. The questionnaire was thereafter translated and changed to fit the purpose in Ecuador. After the completion of the questionnaire it was tested in a pilot test, where random people were asked to fill out the form. Questions that were hard to understand were reformulated and questions were added or removed depending on the relevance for the study and the given answers. A second pilot test was also conducted and the questionnaire was partly changed again.

After the pilot tests the survey was distributed by the authors and by a student of architecture from Universidad Catolica de Guayaquil and with help from the organisation Fundación Huancavilca in Guasmo. The latter organisation was contacted during the preparations for the survey to plan the distribution of the questionnaire. The questionnaire was distributed on foot in the close proximity of the office of Fundación Huancavilca. An employee from Fundación Huancavilca introduced the two authors and the student who conducted the investigation to various people in the area and the students then continued on their own. The students spent one week knocking on doors and asking people if they wanted to participate in the investigation. When conducting the investigation the questions in the questionnaire were read to the participants and the students then noted what the participants answered. The questionnaire was constructed with boxes with given answers to choose from and only few questions with written answers. It contains 18 questions with sub or connected questions, for a more detailed description of the questionnaire see Appendix 1.

When constructing the questionnaire a number of things were taken into account. Sex and age were noted to be able to se if the participants were representative of the area. Then a number of questions were asked concerning the type and material of the investigated houses. This was done to later be able to computer simulate the indoor climate in a standard house of the area. Also questions regarding the thermal comfort of the houses were asked because this is a related issue to the type of house the participants are living in. Furthermore questions of how much gas and electricity each household consumes were asked to be able to calculate the total amount of gas used in the area so that a comparison of the consumption of gas and the calculated maximum amount of biogas that can be produced can be done. Also questions of what type of household articles the participants had were asked. This was done to later be able to estimate the economical standard of the participants.

2.1.1 The Investigated Area

The background information for this study was collected in the close proximity to the Fundación Huancavilca in the south part of Guasmo. The area is divided in zones and sectors as can be seen in Figure 6 and the questionnaire and the collection of organic solid waste were conducted in one sector. The area is marked out on the map and it also has a sector and zone number which is sector Z 351 and zone 2-7. Information was also used from a statistical institute in Guayaquil, INEC (Instituto National de Estadísticas y Censos), from the neighbouring sectors Z 322, Z 346 and Z 352. Information that was received from these areas was construction of houses, waste treatment, electricity and sewage system and what kind of energy they used for cooking. Each of the sectors has about 1200 houses that the information was based on.

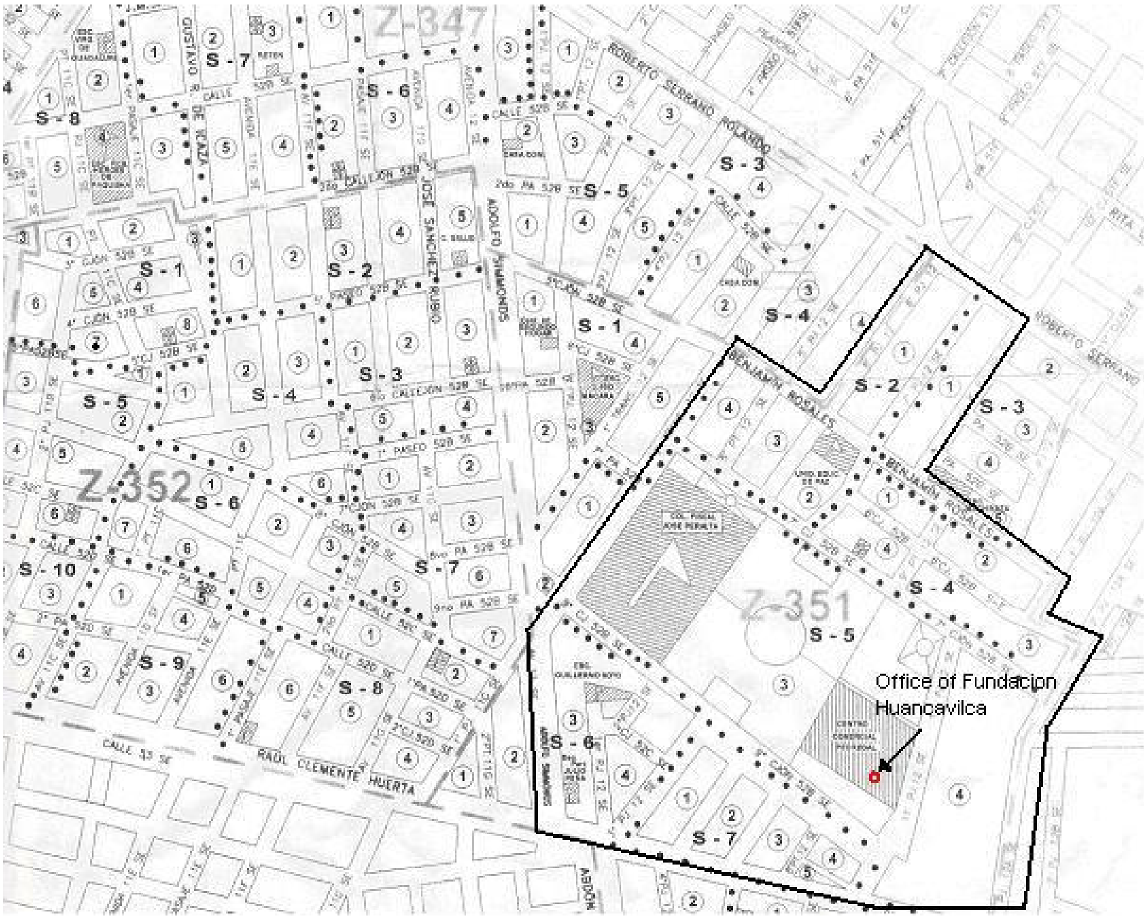

Figure 6. Map over the investigated area in Guasmo.

2.2 Results from Survey of Guasmo

105 questionnaires were gathered in total. Not all questionnaires were fully answered. The number of answers given on every question was between 100 and 105 and only below 100 in a few cases. This the reader can study in further detail below or in Appendix 4. Almost 70 % of the participants were women and 80 % of the participants were between 20 and 60 years old. The participants' opinions on using biogas and separation of household waste in an organic and an inorganic fraction were also investigated and 80 % answered that they were positive to this, see Appendix 4.

2.2.1 Energy Use and Cost

98 % of the participants answered that they have a gas stove and 85 % answered that they use the gas stove more than two hours each day. The use of the gas stoves can be studied in the figure below.

This gives an indication of the monthly consumption of gas used for cooking. In the investigation more than 60 % answered that they buy a new bottle of gas every month and 30 % said they buy two bottles each month which can be seen in Figure 8.

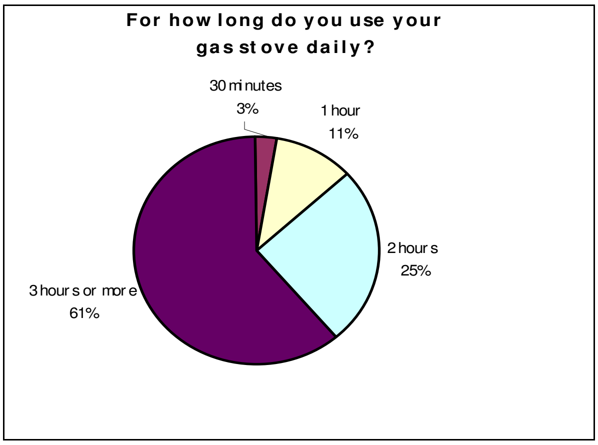

Figure 7: Daily use of gas stove.

During the interviews it became apparent that the normal price for a bottle of gas was $ 2 pretty exactly. 96 Retrieved values of monthly gas cost was noted and each family in mean paid $ 2.7 if the 5 highest and lowest values for gas consumption were taken out with a standard deviation of roughly $ 1.0. Out of 78 retrieved values on monthly electricity cost each family in mean paid $ 21.2 with a standard deviation of $ 18.3. This roughly means that electricity for these families comprises around 9/10 of the whole cost of energy and gas stands for 1/10 of the cost.

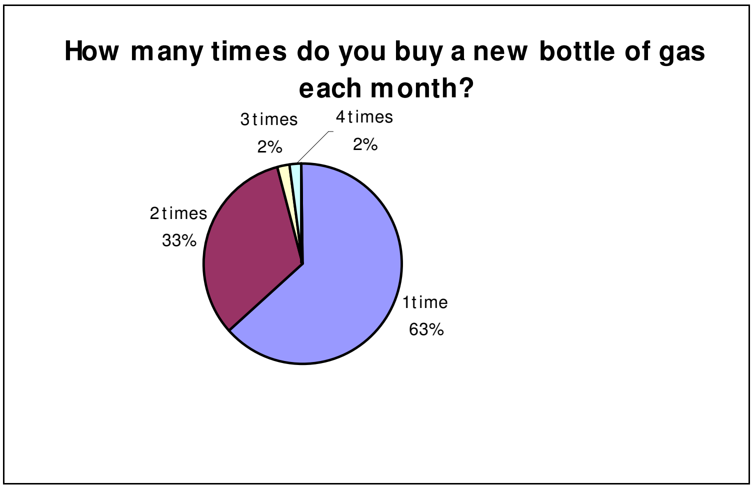

Figure 8. Monthly consumption of bottles of gas.

2.2.2 Houses in Guasmo

Almost 90 % of the participants were living in houses with one floor. 70 % of the participants lived in unfinished houses of concrete blocks with plaster. 15 % lived in unfinished houses without plaster and almost 10 % lived in bamboo houses. Only around 5 % of the houses were finished with windows and plastered concrete block walls as well. 90 % of the houses have galvanized steel roofs and only 17 % of them have ceilings. The galvanized steel is referred to by the inhabitants in Guasmo as zinc. Generally each house had 6 inhabitants with a standard deviation of two and a mean indoor living area of 86 m^2 with a standard deviation of 34 m^2 which also can be seen in Appendix 4.

Figure 9.Pictures of typical brick and bamboo houses in Guasmo.

2.2.3 Indoor Climate

During the winter time, December to April, almost 60 % of the participants thought that the indoor temperature in their houses was slightly comfortable and around 30 % thought it was not comfortable on a five grade scale that is visualized in Figure 10. In summer time, May-November, almost 70 % found the indoor temperature comfortable and 16 % thought that it was not comfortable and which can be seen in Figure 11. This can be connected to the issue of ventilation and in the investigation around 40 % of the participants thought their house had poor ventilation and almost 50 % thought it had acceptable ventilation, very few thought that the ventilation was good or very good in their houses which can be seen in Figure 12. Connected to this result is also the presence of fans. 30 % of the participants had no fans in their houses and 67 % had at least one fan, which can be seen in Appendix 4.

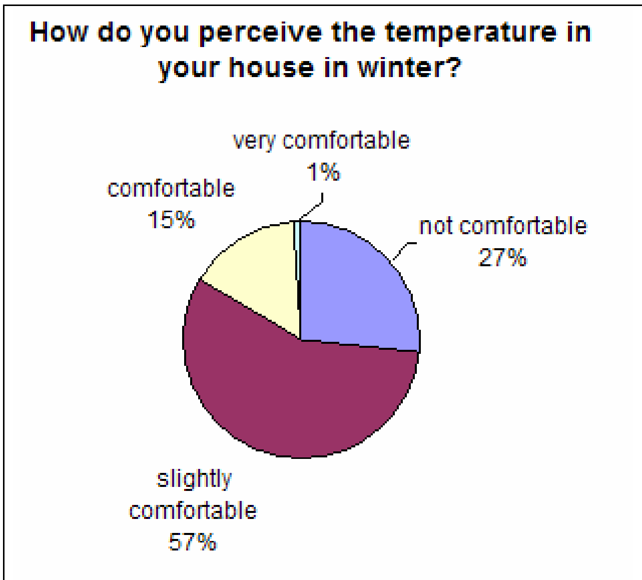

Figure 10. Perceived indoor temperature in winter.

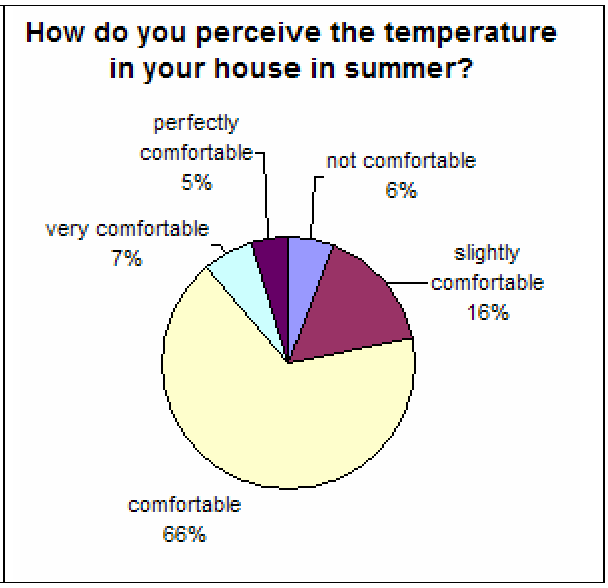

Figure 11. Perceived indoor temperature in summer.

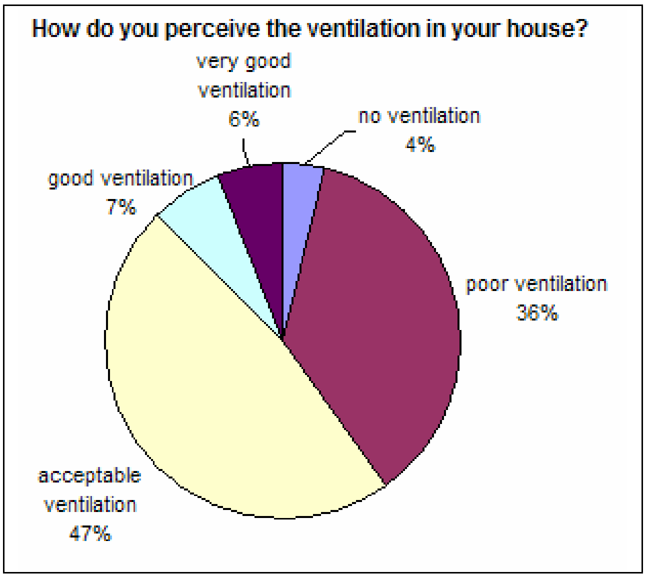

Figure 12. Opinion on ventilation.

Of all of the participants only around 5 % had air-conditioner or hot water but almost 80 % of the participants wanted to have these items in the future. The results from the questionnaire can be studied further in Appendix 4.

2.3 Discussion of the Survey of Guasmo

2.3.1 Energy Use and Cost

Almost every house in the study has a gas stove. They use the stove frequently and used about one or two bottles of gas every month. This is a large energy use in these kinds of households. One normal size tank contains around 208 kWh and considering that one household normally use 1.35 tanks of LPG an approximate use of each household will be around 280 kWh every month. The calculations can be seen in Appendix 5. The calculated mean LPG consumption in Guasmo is lower than the national mean consumption 360 kWh/month and household, see Appendix 2, but it is still considered to be an accurate value. Guasmo is an area with lower economical standard and would therefore use less LPG. It is also a fact that LPG is not only used for cooking which can contribute to a higher national mean consumption.

An interesting comparison is to see which of the types of energy, electricity or gas that has the highest use. On average each participating household uses around 280 kWh of gas and 185 kWh of electricity. Doing a rough approximation one can then say that gas is three fifths of the households total energy use and electricity contributes with two fifths. The absolute majority of households have gas stoves and the gas used in these constitutes the majority of the energy used in the households. But very important to note is that gas only contributes with a tenth of the cost of consumed energy for a family, as mentioned earlier. This fact points to the importance of the economy of a future biogas system. It must be cheap if the economy of the families shouldn't be affected.

2.3.2 Houses and Indoor Climate

One important observation about the indoor climate is that most of the inhabitants that participated in the investigation were unsatisfied with it. 85 % thought that the indoor climate was unsatisfactory during the hot and humid winter time. This is a strong indication of inappropriate housing design. Also important to notice is the fact that around 90 % of the houses have galvanized steel roofs which absorbs solar radiation and emits a lot of the heat into the houses and only one fifth of the investigated houses have ceilings which prevent most of the heat gain from the sun into the houses. Evidently, people that are unsatisfied with their indoor temperature being too high would like a higher rate of ventilation. This seems to be the case when considering that around 70 % of the households in the study has one or more fans. Although it can be considered strange that so many people are unsatisfied with the indoor temperature during the winter period and 30 % still lack the facility of fans in their homes.

2.3.3 Opinions on Biogas

Another important reason for conducting this investigation was to check the public opinion in this geographical area on the issue if they thought that it was possible for them to use biogas produced from household waste instead of LPG. Here the result was uniform too and almost 80 % answered that this was possible and around 20 % said no or that they did not know. To further investigate the possibility of realizing a biogas project, the participants were asked if they thought it was possible for them to separate the household waste in two fractions where one would be organic and the answer was that more than 80 % thought this was possible.

2.3.4 Future Desires of Air-Conditioning

Most of the homes in Guasmo did not have any mechanical climate control except for the fans. However 80 % of the participants answered that they wished to have an air-conditioner in the future. This result might be too high since no economical consequences were implied when asking the question, but it still implies that inhabitants in this area are potential air-conditioning owners in the future. 35 years ago when people started invading the area of Guasmo the standard of living was much lower than today. As the area develops people's demand for comfort increase and it can result in that more families buy air-conditioners in the future.[29]

2.3.5 Validity of Result

When conducting this kind of investigation it is always important to check whether the participants belong to the target group the questionnaire was intended for, otherwise the result can be misleading. Because of this the economical standard of the participants is important and was investigated in a few questions. The first concerned whether the households had air-conditioner or hot water in the showers. The results were uniform and only around 5 % had these two luxury facilities in their homes. This indicates that the group which has been investigated is of relatively low economic standard. Another question concerning the living standard was the number of electronic appliances they had in their homes. It was however hard to make any conclusions from this because of the lack of reference information about what would indicate a lower income family standard. The standard in the investigated houses can only be compared to the standard in the houses that the authors have visited during the stay in Ecuador, and they were in general high-income houses. Be that as it may, the observations of the outside of the houses gave the authors a feeling that the area belong to the low-income class and therefore it is concluded that the participants belong to or are near to the target group the investigation was designed for.

Finally it is important to discuss whether or not the survey was conducted in a proper way and if the results are reliable. First of all it is easily noticed that there is an overrepresentation of women participants in the survey. Probably this is so because the study was conducted around lunch time every day and it seems common that women spend more time in the house during the day cooking and taking care of children and that the men probably are working. Secondly

[29] Adamsson B., O. Åberg, Building Issues, 1993

it was only the gender of the first person spoken to that was noted and often the rest of the family gathered round and helped in providing answers giving the opinion of not only the women but also the children and the men. Thirdly women sometimes know more than the men on some of the issues discussed in the questionnaire, giving more correct answers for example on the issue on how long the gas stove is used daily. In total one can assume that the overrepresentation of women participants therefore does not matter for the validity of the result of the investigation.

The only representation of multistory houses in the investigation was the families spoken to which lived on the ground floors of these houses. This leads to that multiple story buildings might be under represented in the investigation and needs to be taken into account when making general assumptions.

In this study four mean values were calculated, mean living area, number of persons in the household and mean consumption of gas and electricity. The mean value of gas consumption is considered to have the least variation whereas the two others were subject to some insecurity due to large variations in data. However this was taken into account when the means were calculated. The insecurity of the electricity consumption was partly based on lack of knowledge by the participants or the fact that some of the houses have small businesses like shops, billiard halls etc. in their homes and we were seeking the electricity consumption for normal living. The insecurity of the living area was partly based on the authors trying to approximate the living area. But the approximation was also made in consensus with the residents of the houses who did not know particularly well either. The number of persons living in every household was found be 6. This has been verified by data from the statistical institute INEC, reports written by IPUR and in an interview with Luis Salazar, architect in the area of Guasmo.

Table 1. List of variables investigated in the Survey of Guasmo with statistical information.

Parameter	Use of LPG (kWh/month)	Cost of LPG ($/month)	Cost of electricity ($/month)	Living area (m^2)	Number of persons in house
Mean	280	2.7*	21.2	86*	6*
Standard Deviation	100	1	18.3	34	2
No of samples	92	86	78	81	95

* = 5 highest and lowest values have been excluded

2.4 Resumen: Investigación en el Guasmo

El objetivo del cuestionario es recoger información sobre los hogares en el directa residencial del Guasmo. La meta del formulario es documentar el uso de la energía y las condiciones de las viviendas. La investigación fue realizada durante una semana de septiembre en uno de los 30 sectores, Z 351 zona 2-7. El cuestionario fue ejecutado por los escritores, un estudiante de la Universidad Católica de Guayaquil, con ayuda de la Fundación Huancavilca, una NGO activa en Guasmo. Los tres estudiantes fueron presentados en el barrio por un colaborador de Fundación Huancavilca y luego desarollaron solos los entrevistos tocando puerta. El cuestionario en Appendix 1, está diseñado para cuadros con respuestas preparadas, solo pocas preguntas tienen respuestas abiertas. Las preguntas fueron leídas en voz alta y las respuestas fueron anotadas por los estudiantes. 105 cuestionarios fueron realizados en total.

El cuestionario muestra que el 98 % de los interrogados usan gas líquido petróleo (LPG) para cocinar y se usan 1.35 tanques o 280 kWh cada mes. El consumo eléctrico es de un promedio de 185 kWh mensual. Cada familia paga $ 2.7 por LPG y $ 21 de energía eléctrica mensual. El consumo del LPG responde al 60 % del uso de energía total pero solo el 11 % al costo. La gran diferencia en los costos es resultado de los altos subsidios al LPG.

El 90 % de las viviendas en el Guasmo están compuestas por una sola planta construida con bloques de cemento. El 70 % con bloques enlucidos y el 15 % sin enlucir. Los tejados consisten en el 90 % de zinc, de los cuales el 17 % tiene un techo. El 10 % de las viviendas investigadas están construidas en caña y en cada hogar viven 6 personas en una superficie de terreno de 86 m^2. El 90 % de los interrogados consideraba la temperatura interior de la casa como poco agradable especial durante los meses de invierno, que son los meses diciembre a mayo, y al 40 % le parecía la casa poco ventilada. Esta puede ser la razón de que el 70 % poseen un o mas de un ventilador o más y el 80 % le gustaría tener un sistema de aire acondicionado en el futuro.

La opinión de las personas que fueron encuestados sobre la utilización de basura orgánica para producir biogas para cocinar es positiva. El 80 % de los interrogados están dispuestos a separar la basura doméstica en dos lugares y utilizar el biogas en la preparación de alimentos.

La inseguridad en los resultados puede ser grande, principalmente porque la investigación debe entenderse como en realizado en un solo sector del Guasmo. Algunos de los promedios calculados tienen una gran desviación estándar a pesar de que provienen del mismo sector, especialmente el uso de energía eléctrica y la superficie del terreno de las viviendas. El hecho de que la investigación fue realizada a pie tocando las puertas, podría finalizar en un porcentaje bajo en los edificios con departamentos. Se pueden ver los promedios más importantes en los cálculos continuados en la tabla 1. También se pueden estudiar los resultados del cuestionario con mayor detalle en Appendix 4.

3 Investigation of Possibilities for Biogas

In this chapter the possibility for producing and using biogas in Guasmo will be investigated. This will be done because LPG used for cooking has been identified as the biggest use of energy produced from fossil fuels in the *Guasmo Survey Study*. This has been verified by the statistic institute INEC, which can be seen in Table 2. Except for the actual way of producing LPG, biogas differs very little from it and could directly substitute LPG with only minor changes in the distribution system and in the homes. It is therefore an extra interesting alternative in this field of use.[30] The process of producing biogas might also be more energetically efficient in Guayaquil than in European countries because of the constant tropical climate which would decrease the need for heating the process. If LPG was replaced with biogas there would also be a great environmental gain because of the smaller need for international imports of oil and transports plus a more sustainable development in the local area because organic solid waste would not be dumped on the local landfill but used for energy production instead. Yet another positive result of using locally produced biogas instead of imported LPG would be that the area would be less sensitive to a rising oil price and a future energy crisis.

Table 2. Energy source used for cooking in three out of the 30 sectors in Guasmo.[31]

Source of energy for cooking	Houses	%
1. LPG	3 655	97.99 %
2. Electricity	21	0.56 %
3. Gasoline	1	0.03 %
4. Kerex	2	0.05 %
5. Leña o carbon	11	0.29 %
6. Other	2	0.05 %
7. Not Cooking	38	1.02 %
Total	3 730	100.00 %

3.1 Background

3.1.1 Present Use and Distribution of LPG

Every household uses, as discussed previously, 280 kWh LPG every month for cooking which is lower than the mean Ecuadorian use of 360 kWh, see Appendix 2. The consumption can be compared to the Swedish consumption in the housing sector which is 1080 kWh and only 10 %, which is about 100 kWh, of this is for cooking. [32,33]

There are several companies that deliver gas in Ecuador, but the foreign companies like the Spanish Repsol/Duragas has the clear majority of the market.[34] The gas filling plant receives the LPG from stately owned company Petroecuador which has monopoly on importing petrol/gas to the country.[36]

The distribution of LPG in the area of Guasmo and in the whole of Guayaquil is made by lorry. The gas is filled on tanks that are transported to the retailers in the districts of the city. The retailers distribute the LPG in smaller containers to the costumers. The LPG is liquefied

[30] Åberg T, Interview 2007-01-04
[31] INEC, Instituto National de Estadísticas y Censos, Guayaquil, 2001
[32] Swedish Energy Agency, STEM, 2004
[33] Swedish Energy, 2006
[34] Energy Information Administration, Official energy statistics from the U.S Government

by a high pressure to be able to transport more energy in the tanks.[36] LPG consists of a mix of 30 % butane and 70 % propane in Ecuador.[36]

The smaller container used in homes is a 10 kg metal tank filled with 15 kg of LPG.[36] The tanks are brought to the customers homes either via home delivery from a lorry or via delivery boys who bring the tanks on bikes or the customer goes with a cart to the nearest retail shop and brings home the tank him/herself. When the consumer buys a new tank the empty one is turned in for a full one. The returned tanks are filled up again to be redistributed. As mentioned earlier LPG costs $ 2 on the street, which means you get it to your door, but the official price at the retail shops is $ 1.6. If you buy gas for the first time you have to pay an extra $ 35 for the tank.[35] [36]

The LPG is however largely subsidized by government. The real price for one tank of LPG is $ 9.40, which means that $ 7.80 is subsidies. Translated into price per kWh the gas then costs $ 0.05/kWh without and $ 0.008/kWh with subsidies. This costs the government $ 400 millions annually.[37] The energy subsidies in the country stand for 2 % of Ecuador's GDP.[38] The government has an urge to reduce these costs, but have so far been stopped by riots and road blocks initialized by the farmers.[39] The purpose of the subsidy is to improve for the poor population in Ecuador, but both rich and poor get to share the benefits and because the LPG is so cheap it is also used to heat tap water, pools and is even smuggled to neighbouring countries like Peru with higher LPG prices.

3.1.2 Present Waste Collection and Treatment System

The city of Guayaquil has got one waste dump or landfill which is called "Las Iguanas". The landfill is located in the north west of the city in an area called La Cordillera Chongón. The waste is collected by garbage trucks from the different regions of the city and brought here. The households can place their waste in containers or on street corners to be picked up by the trucks. The landfill receives a daily amount of waste of 2453 tonnes of waste and employs 82 workers.[40]

According to statistics from Las Iguanas, every person in Guayaquil produces 0.882 kg waste/person and day.[40] All the waste does however not end up on the landfill. Information from INEC indicates that only 85 % of the households in Guasmo get their waste collected by a garbage truck. Some of the waste is simply put on a pile in the local area, buried, burned or treated by other methods. The percentage of collected waste differs widely for different sectors and regions in the city. In one sector close to the investigated area 25 % of the households treated their own waste.[41]

The households pay monthly for the collection service of waste. The payment for the waste collection and treatment is based on the monthly electricity consumption for each household. Households that use less that 300 kWh/month pay 4.5 % of the minimal salary. Households that use more than that pay 12.5 % of the electrical bill.[40] The minimal salary is $ 100/month, which means that households pay at least $ 4.5 monthly for the waste collection.[132]

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[35] Hoy Online, 2006-11-21
[36] Engineer Mario Mena Aspiazu, Chief of Engineering and Maintenance, Repsol/YPF, interview, Guayaquil, 2006-11-16
[37] Hoy Online, 2006-11-21
[38] World Bank, 1995
[39] The Economist, 2001,
[40] Dep. ASEO Cantonal, Mercados y Servicios Especiales, aug 2006
[41] INEC, Instituto National de Estadísticas y Censos, Guayaquil, 2001

The waste was not treated at all about 10 years ago, only collected and put in a pile on the landfill. However the government realized that the untreated waste contaminated the environment. Now the collected waste is put in small piles and covered by sand in Las Iguanas. Chimneys and filters collect the gases and liquids from the landfill. The produced gas from the waste is burned.[40] If the waste is degraded in anaerobic environments like this without burning or collecting the released methane it will have an effect on global warming 20 times greater compared to the effect from carbon dioxide.[42]

3.2 Method of Biogas Investigation

The general method for determining the possibility of producing urban biogas to replace LPG was to collect sufficient background information to be able to select two suitable biogas production systems, and evaluate production efficiency and economy for these systems in Guasmo and then compare it with the present system.

The investigation was initialized by both calculating the daily consumption of LPG and the annual consumption for the whole of Guasmo. From the information in the questionnaire a required production of biogas to cover the use of LPG in Guasmo could be calculated. The LPG consumption was translated into consumption of biogas by using the heat value of methane.

After the assessment of the biogas consumption in Guasmo was made, samples of the organic waste from 10 families in the same area were collected during five days. The investigation was performed in the same area as where the questionnaire was executed. The collection of organic solid waste was done to retrieve data on the organic waste production and composition in Guasmo. It was also important to investigate if it was possible to source separate the organic waste in Guasmo. The samples were collected by placing out one container with an empty plastic bag for collection of the organic solid waste in each house, instructions on how to source separate the organic waste were also given. The plastic bags were collected after 24 hours and replaced with new ones. Each sample was then weighed and the contents registered visually and noted. After this a smaller representative sample of about 50-200g from each larger sample was taken and its water content was measured by drying and weighing it in a laboratory at the Catholic university in Guayaquil. This was done by first weighing the sample, then vaporising the water in each sample in an oven at 105° C for 24 hours, then the sample was weighed again. The weight difference is the water contents and the value was compared to the former weight for a moisture concentration.

After this the samples were to be inserted in the oven again but this time at 550° C for a shorter time of 15 minutes and then weighed one last time. This would have been done to retrieve the volatile solid contents of the 50 samples and from that a mean carbon concentration could be calculated. The carbon concentration would then be used to calculate the potential biogas amount that can be produced from the organic household waste from the Guasmo area.[43]

However it was not possible to execute the high temperature combustion in Ecuador, mainly because no adequate oven was available. The carbon concentration was therefore calculated theoretically. A nutrient table was used to produce a mean ash concentration for the found waste materials. Since the waste samples comprises of three parts; water, carbon and

[42] Sterner O., 2003
[43] Norweco, Norwalk Wastewater Equipment Company Inc., 1997

inorganic compounds (ash) the carbon concentration could be calculated by subtraction when moisture and ash concentrations were known.

Lastly two suitable biogas production processes were investigated and the production and economy for these were calculated. These biogas reactors were large scale and appropriate to the waste from Guasmo regarding to the mass and composition. The choice of process also took hygiene demands and climate under consideration. The reactors were both real plants and payback time and gas price were calculated from the known investment costs, running costs and revenues. Information from Ecuador like gas price and cost for waste collection was used to get reliable calculations. The values of production rates of biogas that were used in this study were taken from plants working in Europe. Since the compositions of the waste might be different in Ecuador, the production rate might also be different. The quality of the waste from Guasmo was therefore used to calculate the maximum production rate from the waste. This was compared to the production rates for the plants to see if the assumption was reasonable.

3.3 Delimitations

The collection of solid organic waste and the *Survey study of Guasmo* were limited to only one sector of Guasmo, Z 351. Only large scale biogas production will be investigated in this thesis and it will be done through literature studies. A large scale biogas plant of course needs lots of space but the location of such a plant will not be investigated in this thesis because it is considered to be a minor problem under the circumstances. Among the large scale biogas plants only continuously fed one step systems will be investigated as these are the most economical ones on the market. Large scale batch reactor systems will be excluded from the investigation because these generally have a lower efficiency compared to continuously fed systems. Also small scale biogas production will be excluded from the investigation as was said in the foreword. They are so because of the numerous problems that will occur if small scale biogas was to be implemented in an urban area.

3.4 Biogas Theory

3.4.1 Anaerobic Digestion Process

The biogas production system is basted on anaerobic digestion (AD) of organic material by micro organisms under oxygen-free conditions. The biological process has developed over the years and there are several different kinds adapted to different waste materials.[44] The degradation process takes place in four steps where the end-product is biogas, consisting of carbon dioxide and the desired energy-rich methane gas. The different steps are called hydrolysis, acidogenesis, acetogenesis and methanogenesis. The first stage involves the fermentative bacteria that hydrolyse and ferment insoluble organic compounds such as proteins and carbohydrates to monomers, such as amino acids, sugars, ammonia and fatty acids. In the second stage acidogenic bacteria convert the monomers to volatile fatty acids, such as acetic, acid, propionic acid, butyric acid where after acetogenic bacteria produce acetic acid, hydrogen, carbon dioxide, alcohol and other simple organic compounds out of the volatile fatty acids. In the fourth stage methane is produced which can be formed from acetic acids or hydrogen and carbon dioxide.[44] An overview over the process can be seen in Figure 13. The amount of produced biogas is depending on the process design and waste type and amount.[45]

[44] Charles C. Ross, P. E. Thomas Lefferson Drake, July 1996
[45] Regional Information Service Center for South East Asia on Appropriate Technology, Institute of Science and Technology Research and Development, Chiang Mai University, November 1998

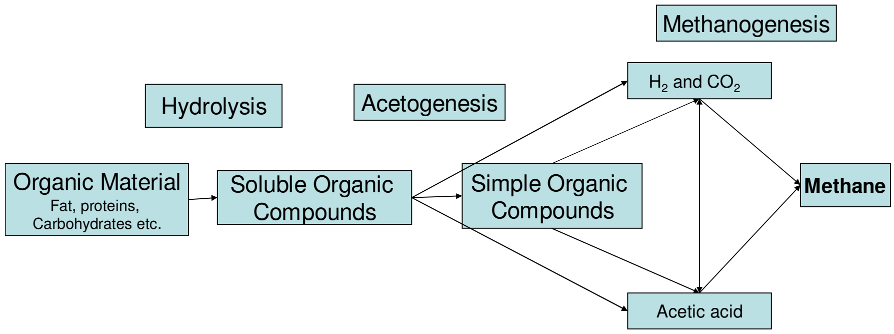

Figure 13. Overview of the anaerobic digestion process.

The AD process has two optimal working temperatures, one mesophilic that is around 35°C and one thermophilic of 55°C. The thermophilic range has got the highest efficiency. These two thermal ranges can be combined in two stage systems.[46] Test made by *Patal H, et al., 2002* shows that a higher biogas production can be obtained by using higher temperature.[47] However at thermophilic conditions the process becomes more sensitive to disturbances.[48]

There are some important parameters which control the process and one of them is the pH-value. For example the slow growing methanogenic bacteria suffer from growth inhibition if the pH-value drops below 6.5 or exceeds 8.5. Therefore it is important to keep the pH-value up in the initiation of the process when the production of volatile fatty acids is high. Sometimes this is done by adding lime stone to the process. It is also important to keep the pH-value down towards the end of the process when the consumption of N causes elevated levels of ammonia and the pH-value can rise to around 8.[46] Another important parameter apart from the temperature and pH-value is inhibiting or toxic substances. Examples of these are detergents such as soap, antibiotics and organic solvents.

3.4.2 Type of Waste and Pre and Post Treatment

When talking about waste treatment one normally classifies waste as either grey waste which is a mixed stream of MSW (municipal solid waste) that can include metal, glass, plastics and organics, or OFMSW (Organic Fraction of Municipal Solid Waste). In this project we are evaluating the possibility of handling the organic fraction of municipal solid waste. OFMSW can be either mechanically sorted or separated at the source, if the latter it is normally known as bio waste or the vegetable fruit garden fraction (VFG).

Depending on the type of raw material that is to enter a biogas process there has to be different pre-treatment arrangements. When treating MSW in an AD-process there is a health risk and a hygienisation comprising of heating the material to 70°C for one hour is recommended.[46] For AD-processes that use a waste that is not a slurry or a liquid the pre-treatment arrangement usually are magnetic separation of metals, shredding of raw material into smaller pieces, pulping or mixing of the raw material with already inoculated material and then some kind of screening process in which too large pieces are sorted out. The material is then pumped into the reactor chamber and the AD begins. The difference between dry and wet systems in pre-treatment requirements is that for a dry process normally heavy more durable equipment is used. Generally a wet process needs more advanced pre-treatment

[46] Regional Information Service Center for South East Asia on Appropriate Technology, Institute of Science and Technology Research and Development, Chiang Mai University, November 1998
[47] Patle H., D. Madamwar, 2002
[48] Murto M., Interview 2006-08-15

arrangements and *G. Lissens, et al., 2001* write that in wet OFMSW systems there is a VS loss of about 15-25 % due to the more complicated pre-treatment steps such as the use of screens, pulpers, drums and the creation of a scum layer which has to be removed.

The quality of the OFMSW is described both by the content of total solids (TS) and by the concentration of volatile solids (VS). The TS is the percentage of a samples weight minus its moisture content and the VS is the organic fraction of the TS. The organic fraction is comprised of compounds containing carbon, such as fats, carbohydrates and proteins and more. The VS-content of the waste is measured in a test called "2540 Solids".[49] The VS can further be divided into two subgroups one which is easily degraded and one which contains lignin-substances which are not readily degradable. The fractions are called BVS (biodegradable volatile solids) and RVS (refractory volatile solids).[50] Another thing important for a material to be disposed of by AD is the Carbon (C)/Nitrogen (N)-ratio. A material with a C/N-ratio of 20-30 is considered to be optimal for AD. Animal discards such as cow dung has a mean C/N-ratio of 24 and MSW has a mean C/N-ratio of about 40 but for example some substances have much higher C/N-ratios still, more examples are found in the table below.[51] The composition of the raw material affects the yield and quality of the biogas as well as the quality of the compost.

K. Braer, 1995 writes that after MSW is treated in a dry process the digested material is usually dewatered mechanically and matured aerobically to compost which then can be used for farming. There will be an excess effluent that can be used for inoculating of the incoming MSW but since it probably will be in excess it will have to be spread on farmland or treated in a wastewater plant as well.

Table 3. C/N-ratio for some substrates.

Substrate	**C/N-ratio**
Human excretes	8
Chicken dung	10
Cow dung	24
MSW	40
Maize straw	60
Wheat straw	90
Saw dust	>200

3.4.3 Anaerobic Digestion Systems

There are many types and classifications of biogas reactors. One classification is the frequency of adding material to the process. Two general types are mentioned, continuous fed reactors and batch reactors. The batch reactor is stopped, emptied and filled up again for every cycle. The batch reactor is according to *G Lissens, et al., 2001* the least complex process due to its simple design. These are important reasons for the batch-process being a high potential solution in developing countries. A continuous reactor can as the name reveals be fed with waste material continuously. Continuous reactors are divided in one or two stage systems. The two stage systems have a larger resistance toward toxic and inhibiting substances such as high ammonia concentrations. The one stage system is more vulnerable but is cheaper and less complex compared to the two stage systems and therefore more frequently used.[52] Examples of one stage rector processes are: the Dranco, the Kompogas and the Valorga processes.

[49] Norweco, Norwalk Wastewater Equipment Company Inc., 1997
[50] Kayhanian, M., 1995
[51] Regional Information Service Center for South East Asia on Appropriate Technology, Institute of Science and Technology Research and Development, Chiang Mai University, November 1998
[52] Lissens G., P. Vandevivere, L. De Baere, E. M. Biey, W. Verstaete, 2001

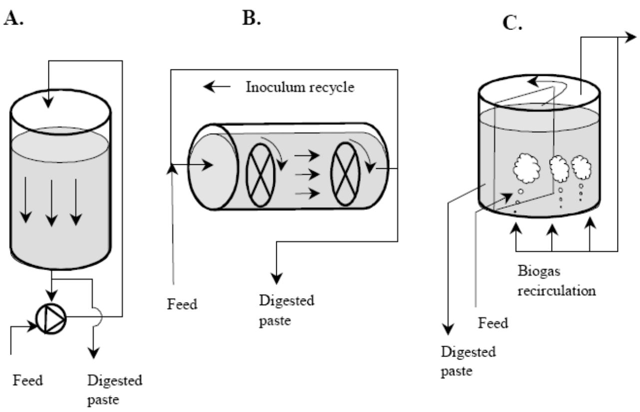

Figure 14. A is the Dranco-process, B is the Kompogas-process and C is the Valorga-process.[53]

Biogas reactors are also classified depending on the waste quality, measured in total solids (TS). A system that works with TS contents between 20-40 % is called dry system and the wet system works with a TS content less than 15 %. The dry system has proven to be the most reliable system due to the more robust feeding system required for the low viscosity waste. It is also more reliable due to the lower risk of being inhibited by e.g. high concentrations of ammonia. This is so because if high concentrations of ammonia occur it is contained within a smaller volume of the reactor due to the slower mixing process in a dry-system compared to that in a wet-system. In a wet-system the ammonia is more easily spread to the whole of the volume and thereby is more prone to damaging the whole of the process.[53]

During the decomposition organic materials are hydrolysed and reduced to methane, carbon dioxide, ammonia, hydrogen sulphide and vapour. All except methane are unwanted by-products that lower the heat value for the biogas. They can also cause problems like corrosion and slower production of methane.[54]

The biogas reactor needs to be dimensioned so that all waste can be treated. A value that measures this is the organic loading rate, which gives the conversion capacity for the process. The organic loading rate (OLR) needs to be held on an appropriate level for the reactor so that the production of inhibiting substances is kept low, if the OLR is exceeded the process can go sour. The OLR is depending on the type of waste material, concentration and the flow. Different processes can handle different values of OLR. A dry system can according to *G. Lissens, et al., 2001* work with higher OLR values. An example of this is the dry biogas reactor in Brecht, Belgium that can work with an OLR value of 15 kg VS/m^3, day whereas a wet system typically has an OLR value between 5 and 10 kg VS/m^3, day. Also *G. Lissens, et al., 2001* writes that for digestion of OFMSW the OLR_{max} will largely be determined by the growth rate of the acid producing and hydrolysing bacteria and by the growth rate of the methanogenic bacteria and that this is especially true for the VFG-fraction which generally is highly biodegradable.

3.4.4 Production Rate

Organic material basically consists of fat, proteins and carbohydrates. The production rate of biogas depends on the composition of the raw material. At complete digestion one kg of fat

[53] Lissens G., P. Vandevivere, L. De Baere, E. M. Biey, W. Verstaete, 2001
[54] Regional Information Service Center for South East Asia on Appropriate Technology, Institute of Science and Technology Research and Development, Chiang Mai University, November 1998

gives 0.85 Nm^3, one kilogram of protein gives 0.5 Nm^3 and one kilogram of carbohydrates gives 0.4 Nm^3 of methane.[55]

According to *K. Braer, 1995* the production rate for OFMSW is normally between 100 and 200 Nm^3 of biogas/tonne of bio waste. He also writes that the produced biogas contains between 55 and 70 % methane, 30-45 % carbon dioxide and 200-4000 ppm hydrogen sulphur (H_2S). He also mentions that a biogas plant with pre- and post-treatment consumes around 20-40 % of the energy content in the produced biogas for e.g. heating and mixing in the process.

3.4.5 Upgrading Process

After the biogas has been produced it might need to be upgraded depending on what it is going to be used for. This needs to be done for example if the gas is going to be fed into a natural gas grid, be fuel for cars or if it is going to be filled on tanks and used in gas stoves.

Today Sweden is the country in Europe which has the most experience of upgrading biogas to natural gas quality fuel and has more than 10 years of experience of this. The first plant for upgrading biogas in Sweden was built in 1992 and since then there has been a steady development of the technique. In Sweden 4 methods of upgrading biogas are used; re-circulating water scrubber, PSA (Pressure Swing Adsorption), absorption with Selexol and chemical absorption. Re-circulating water scrubber is the most common and PSA the second most common whereas the other two are far less used.

Upgrading biogas is a process which really comprises of two parts; cleaning the gas and then upgrading it. The cleaning process is to separate particles, water and sulphur-hydrogen (S-H) compounds which can damage equipment like metal pipes and tanks through corrosion. The upgrading process is to separate carbon dioxide from the gas to elevate the heat value, sometimes higher hydrocarbons such as butane and propane also must be added to the gas during the upgrading process to make the heat value of the biogas equal to that of natural gas.

The sulphur-hydrogen substances can be separated from biogas in several different ways, one of them is by adding Fe^+ ions directly to the digestion chamber. The iron-ions then form the in-solvable iron salt FeS, which later exits the process with the digested residue. This is also good for the biodegradation process. To separate water from the biogas also several different methods can be used, but adsorption-dryers are the most common. The choice of water separating method much depends on the choice of method to separate carbon dioxide from the biogas.

The PSA upgrading-technique is based on separation due to molecular size and presence of physical forces. The upgrading is conducted under elevated pressure and the absorption material is regenerated via pressure reduction. Generally the distributors claim a methane loss of no more than 2 % for both PSA and water scrubber systems but this can be higher and is important to measure during the production.[56]

[55] Swedish Association on Biogas (SBGF), November 2004
[56] Persson M., November 2003

The investment cost for an upgrading system depends on the capacity in Nm^3/h of the system and the higher the capacity the lower the cost. For a system between 100 and 350 Nm^3/h the cost is between \$ 3570-6430 and there is no substantial difference between PSA and water scrubber systems. The production cost for upgrading biogas varies between \$ 0.014-0.057/kWh upgraded gas and to specify it more it can be subdivided into two different sizes of production rates. Production cost for a system smaller than a 100 Nm^3/h is \$ 0.042-0.057 and for a 200-300 Nm^3/h system production cost is \$ 0.014-0.021/kWh upgraded gas. The cost is calculated on an exchange rate for the \$ of 1 to 7 for the Swedish crown.[57]

Figure 15; PSA biogas upgrading system

3.5 Results of Biogas Investigation

3.5.1 Amount of Waste

From the same area as the survey study was conducted 49 samples of organic solid waste were collected from 10 families. The collection was executed after lunchtime every day between one and two in the afternoon and the waste was weighed and analysed shortly after. Originally 50 samples were planned to be collected but one sample was not collected because this family had been cooking in another house that day and did not produce any waste. A total weight of 67.1 kg was collected during 5 days. The amount of produced waste varied widely for the different households and days of the week. The weight of the waste could vary between 0 and 5.2 kg which can be seen in Figure 16.

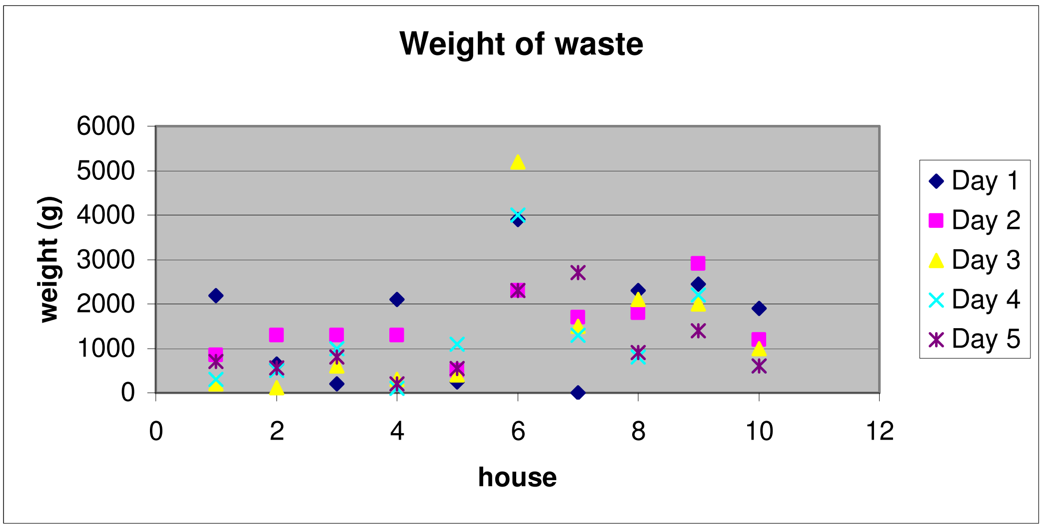

Figure 16. Weight of waste from the households 1-10 for the five days.

The calculated mean amount of waste collected per household therefore had a very high standard deviation. To get a more statistically viable value waste peaks and drops were

[57] EuroInvestor, 2006-12-14

excluded. The new calculated mean without the five lowest and highest values was 1.2 kg with a standard deviation of 695 g which can all be seen in Appendix 3. The amount of collected waste reduced towards the end of the week which can be seen in Figure 17.

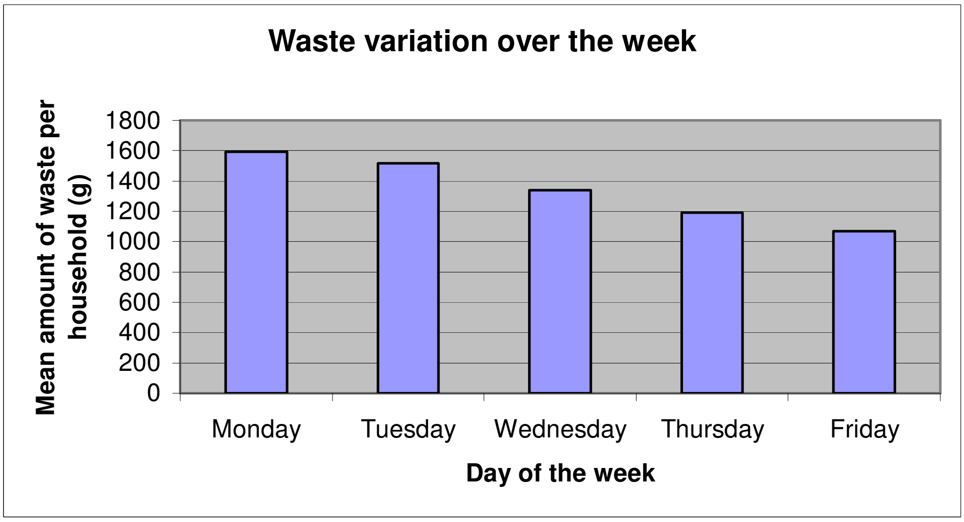

Figure 17. Waste weight variation over the week.

The households participating in this investigation were chosen from the families that participated in the survey study of Guasmo. The number of family members in each household was noted but this information was sadly lost and we were only able to recover the number of family members in 6 of the families. The calculated mean production of organic waste with the known number of members in the family was 260 g/day and person. When calculating the mean production of organic waste based on the mean number of family members from the Guasmo survey, which was 6 persons, it is 210 g/day and person. With the above estimated daily mean production of organic waste of 1.2 kg/family and about 200000 inhabitants and a mean family number of 6 persons, the whole of Guasmo produces 14600 tonnes of OFMSW annually.

3.5.2 Quality of Waste

Every bag of waste was visually analysed and every component of importance in the mix in the sample was given a percentage of the total content in the sample. The waste mostly contained peals of fruits, vegetables and rice. The ten most common components are visualized in Figure 18. All of the noted components have been used to calculate the quality of the waste, but to make the figure easy to read components which made out a smaller part than 2 % of the total contents have been gathered in the "Rest" post. When analysing the waste, the different components have been equalized to the inside of the fruit and vegetable even though the waste contained mostly peals.

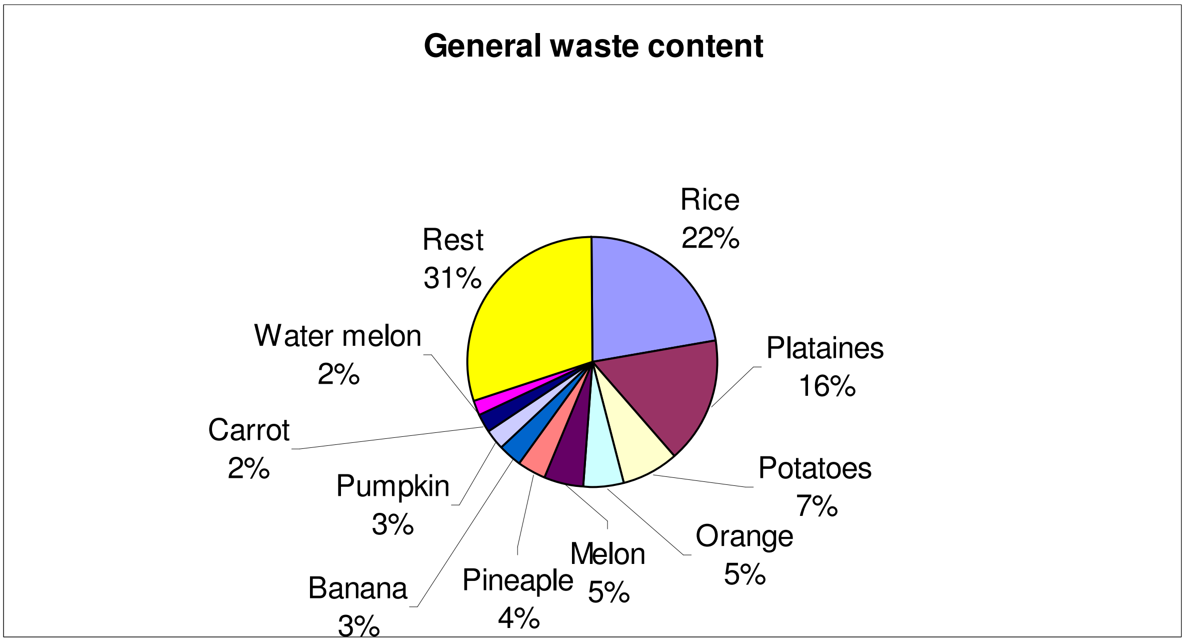

Figure 18. General content of the waste in mass % of samples 11-50.

Moisture concentration was measured and calculated to 76 % by drying all the small samples of waste, calculating a moisture concentration for each one of them and then calculating a mean out of these 49 samples, see Appendix 12. Logically this means that the waste has a mean concentration of total solids (TS) of 24 %. From the concentration of total solids the mean ash concentration was calculated to 0.7 %. This was done by investigating the composition of every component in the sample mixes with nutrient tables. Every component was assumed to be composed of six parts; water, fat, proteins, carbohydrates, fibres and lastly an inorganic part or ash concentration. The ash concentration was given directly by the nutrient tables or derived by subtracting the 5 other parts from the investigated component in the sample mix. The mean carbon concentration in 49 samples, or the VS content for the organic fraction of solid waste in Guasmo, was thereafter calculated to 23 % by subtracting the ash concentration from the TS. The calculations can be seen in Appendix 11.

For calculating the mean VS composition the components with the 20 highest mass percentages were used. These components were taken from samples 11-50 because on the first day of the waste collection when the first 10 samples were taken only the weight and not the mix of the samples were noted. For each of the 20 components the total mass was calculated, this gave for example the total mass of rice, plataines, potato etc. from the 40 samples. From each of these 20 masses the amount of fat, proteins, hydrocarbons and fibres was calculated with nutrition tables and the VS composition could be derived. This can also be seen in Appendix 11.

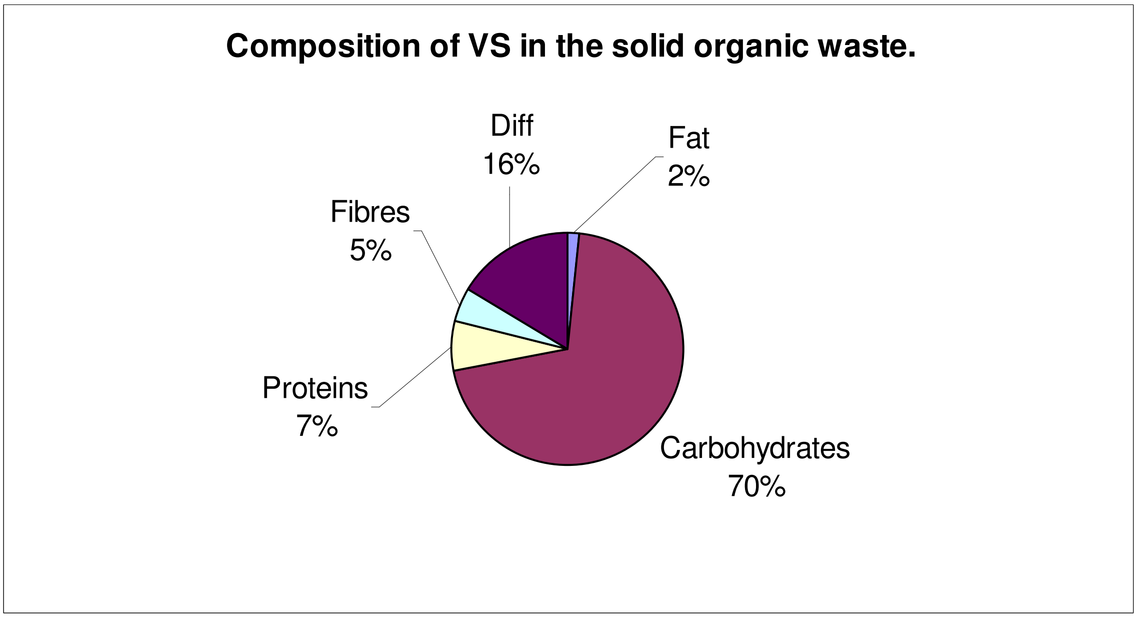

Figure 19. Nutrient content of the organic part of the waste.

The post "Diff" comes from that only 20 components out of the total of 37 were investigated. This means that this mass is undefined as to content of fat, proteins, carbohydrates, fibres and inorganic compounds. The total weight of the 40 samples for which the VS composition is based on is 51.2 kg and the composition is illustrated below. Here we can also see the post "Diff and fibres", it comes from that fibres make out 1.068 % plus the post "Diff" from above which makes out 3.84 %.

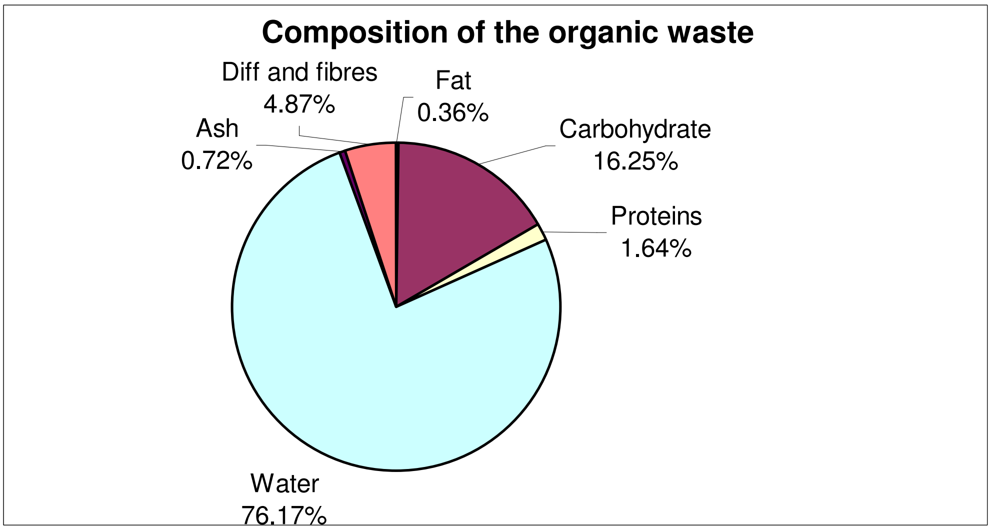

Figure 20. Mass composition of the waste from 49 samples.

3.5.3 Theoretical Maximum Production of Biogas

The theoretical approximation of the maximum production of biogas in Guasmo can be calculated from the amount of VS, recall that Guasmo produces 14 600 tonnes of OFMSW/year and that the VS concentration is 23.15 %. This means that 3379 tonnes of the OFMSW can be converted to biogas every year. The mass composition of the 3379 tonnes of VS produced annually can be seen in Figure 21. The methane production from fat, proteins and carbohydrates from the passage "Production Rate" in the *Biogas Theory* chapter 3.4.4 is used and these masses are converted to amounts of energy. Finally the amounts of energy from each substance are added and a total theoretical maximum production from the VS is derived. The gas from the rest post is assumed to have the same production of methane as carbohydrates to not overestimate the biogas potential in this material, even though it probably has the same composition as the investigated material and therefore should be somewhat higher.

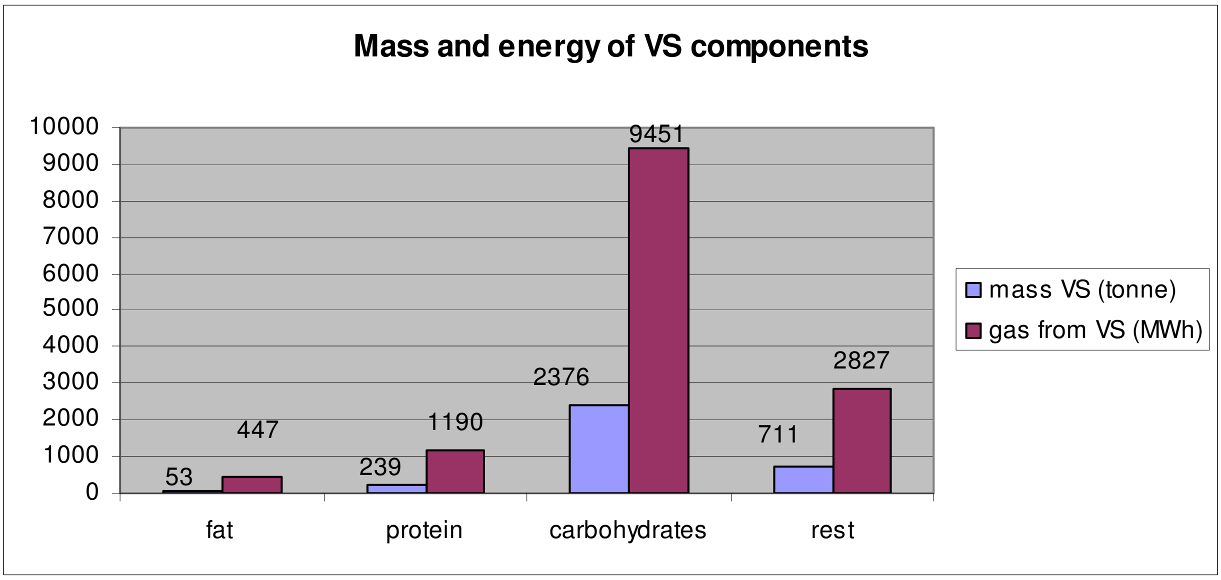

Figure 21. Mass and produced energy from the different components in the waste

The estimated sum of the produced biogas is 13.9 GWh/year. The gas consumption of a normal household in Guasmo is 9.33 kWh/day. This makes the total annual consumption of gas in Guasmo 112 GWh. From this it can be concluded that the maximum production of biogas from Guasmo, if it is assumed to be 13.9 GWh, can cover 12.4 % of the needed gas for the area.

3.5.4 Appropriate Biogas Reactors for Guasmo

The biogas reactor has to be large enough to treat the whole organic waste fraction from Guasmo. For this type of large scale reactor the capacity will have to be above 14600 tonnes sorted organic waste annually. The waste from Guasmo has a TS concentration of 24 %, which means that the anaerobic digestion process can be either a medium solid- or a high solid process. Even though Guasmo is close to a river from which water could be added to the process, low solid systems are assumed inappropriate due to the larger reactor volume required and complicated and expensive post treatment of the large amounts of used water. The high solid systems are more robust as well. Batch reactor systems use many small reactors that can be started when the appropriate amounts of waste is collected. Even though batch reactors are considered by experts to have great potential in developing countries because they are simple and inexpensive. The fact that batch reactors have 40 % lower biogas yield than continuously feed one-stage systems makes this process an inappropriate solution for Guasmo as well.[58]

Even though the technical knowledge in Ecuador is high, the biogas technique is a new technology. The process needs to be managed with as few disruptions as possible and the more simple and robust technique possible the better. The multistage biogas plant is a newer

[58] Lissens G., P. Vandevivere, L. De Baere, E. M. Biey, W. Verstaete, 2001

technique, more complicated and expensive. The suggested process is therefore a single stage high or medium solid reactor which is a more reliable model. The reactor can use either mesophilic or thermophilic conditions. The mean temperature in Guayaquil is 25.7°C and the temperature has small annual and daily variation, which means that the mesophilic process doesn't need to be heated so much. Heating is needed for the thermophilic process but less than in colder climates.[59 60]

Two appropriate reactor models are found that can suit these conditions. The two reactors are real projects that are running today. The first is a Valorga process in Tilburg, Netherlands and the second is a Dranco process in Brecht, Belgium.

The Valorga process is a French technique developed by Steinmuller Valorga Sarl and the process technique can be studied in the theory chapter and in Figure 14. The process can handle source separated municipal solid waste but can also handle grey waste. The process is a single stage system that works with a TS concentration of 20-35 %. The reactor is designed as a concrete vertical cylinder with the diameter of 10 m and the length of 20 m. The Tilburg plant in the Netherlands was started in 1994 and has a capacity of 52 000 tonnes/year. The total reactor volume is two times 3300 m^3 with the retention time of 20 days. The plant is processed in the mesophilic range at around 40°C and produces 80-85 Nm^3 biogas/tonne sorted waste with a methane concentration of 56 %.When the plant was constructed in 1994 the capital investment costs for the plant was $ 17 500 000.[59] Below is a picture over the Valorga reactors in Tilburg.

Figure 22. Picture over the Valorga plant in Tilburg. [61]

The second appropriate reactor uses a Dranco process. This single stage reactor in Brecht, Belgium works with a thermopile high solid process. The reactor has a maximum capacity of 20 000 tonnes per year but receive in mean 17 500 tonnes yearly.[62] The reactor has a volume

[59] Shefali V., 2002
[60] Meteonorm 4.0
[61] Biomass-Using anaerobic digestion, 2006
[62] Organic waste systems, OWS, 2006

of 808 m^3 and the tank is 21 m high. The process has a retention time of 20 days and gives a biogas yield of 100-120 Nm^3/tonne source sorted bio waste and a methane concentration of 50-60 %.

Capital investment cost for this plant, that was constructed in 1992 was according to *R. Sinclair, et. al., 1995* $ 4.7 millions. This investment cost excluded scales and a waste water treatment plant from a previous landfill operation. *S. Verma., 2003* writes that the investment cost for the Brecht plant with this equipment was $ 6.1 million. It was not possible to receive values for the running cost of neither of the plants so these have been approximated to one twentieth of the capital investments cost/year.[63] Below is a picture over the two biogas reactors in Brecht. The reactor appropriate for Guasmo is the Brecht I.

Figure 23. Overview over the the Brecht plant, with Brecht I in the background.[64]

Table 4. Shows the most important data for the two processes.

Location	Start-up	Process	Capacity (tonne/year)	Methane concentration	Production (Nm^3 biogas/tonne OFMSW)	OLR(kg VS/m^3, day)	Operational Temp.
Tilburg, Netherlands	1994	Valorga	52 000	56 %	80-85	5	40°C
Brecht Belgium	1992	Dranco	20000	50-60 %	100-120	15	50-58°C

3.5.5 Distribution of the Biogas

The purpose of collecting organic solid waste and producing biogas was to substitute the LPG used in the residents for cooking. To make this possible the biogas has to be transported in someway to the houses. The biogas can be transported in pipelines or in tanks by lorries. Depending on the distribution system the gas has to be either cleaned or upgraded or both.

[63] Sinclair R., M. Kelleher, 1995
[64] Renew LA, City Council, 2006

The distribution system and economical prerequisites will change depending on the location of the plant. The gas can be distributed in pipes to every household but this requires a very developed infrastructure. Guasmo is an area that lack sewage systems in several places and probably the sewage system will be completed before a gas grid will be constructed, which makes a gas grid an unrealistic option today.

The same LPG tanks that are used today can also be used to transport biogas. If these tanks are to be used, the gas needs to be cleaned and upgraded. The tanks are made of metal and the sulphur in the biogas would damage the metal.[66] LPG and biogas have two different heat values and according to the ideal gas law a tank can only contain the same amount of moles of biogas as LPG if the pressure is to be the same. The heat value for biogas is only 20 % of the heat value for LPG. This means that more biogas needs to be pushed in to the tank to get the same amount of energy in. To achieve the same energy content from biogas with a methane concentration of 55 % as from LPG a pressure of about 41 bar would be needed. The tanks used for LPG are normally used with a pressure of about 7 bar.[67] To transport the same amount of energy of biogas upgraded to natural gas quality in a LPG tank a pressure of 23 bar would be needed. If the upgraded biogas would be distributed at the same pressure as for the LPG, the tank will contain only a third of the energy.

Figure 24. Picture of LPG tank.[65]

3.5.6 Production of Biogas from the Appropriate Reactors

From the information about the plants a production of biogas could be calculated. This was done from the known production rates of biogas the different reactors had. Since the use of energy for cooking was known a covering ratio could be calculated for the plant. This can be interpreted to be how much one single household could lower their use of LPG or the percentage of houses in Guasmo that could be supplied with biogas for cooking.

The Valorga reactor has a maximum capacity of 52 000 tonnes yearly and the production rate is as mentioned in Table 4 between 80- 85 Nm^3 biogas/tonne sorted organic waste. This means that the reactor produces 1 168 000 Nm^3 biogas every year, based on the lowest production rate. The concentration of methane in the biogas would be, as mentioned in Table 4, 56 % which means that the energy from the produced biogas would be 6.4 GWh/year. This leads to a covering ratio of 5.7 %.

The Dranco process is assumed to receive the same amount of waste, 14 600 tonnes, but the production rate from this plant is higher. The production is set to 100 Nm^3 biogas/tonne source sorted organic waste, but can vary between 100-120 Nm^3/tonne source sorted organic waste with a methane concentration of 50 %, which means that the Brecht plant has a production of biogas of 7.26 GWh per year. This means that the covering ratio for this plant is

[65] Boman Forklift, 2007
[66] Murto M, Interview 2006-08-15
[67] Engineer Mario Mena Aspiazu, Chief of Engineering and Maintenance, Repsol/YPF, interview, Guayaquil, 2006-11-16

higher than for the plant in Tilburg and 6.5 % of the households in Guasmo would be able to use biogas for cooking if the Dranco process was applied.

3.5.7 Production Costs for the Different Reactors

Calculations with the annuity method show that both a Dranco and a Valorga plant would be a bad investment even if the biogas could be sold for the present unsubsidized LPG price of $ 0.05/kWh. The gas would have to be sold for at least $ 0.17/kWh for the Dranco process and $ 0.19/kWh for the Valorga process if the plants were to be profitable. (Appendix 9)

The calculations are made for a reactor that can handle 20 000 tonnes of OFMSW/year and with an economic lifetime of 20 years for the plant. 20 000 tonnes is more than the required weight of waste but it is needed to handle variations in the flow. Labour, service and maintenance costs are assumed to be one-twentieth of the capital investment cost and the interest rate of return is set to 10 %.[68] This calculation does not take into account that the plant has a residual value after 20 years. This plus the fact that the interest rate of return and the cost for running, maintenance and administration of the plant are relatively high makes it a conservative calculation.

In the calculations the revenues from the plants have been approximated. The revenues apart from selling the biogas are tipping fees and compost. The tipping fee is $ 120 /tonne OFMSW in Belgium. These fees have been adapted to the fees that the households in Ecuador pay every month for the service of waste collection. The price is depending on the electrical consumption. The households that consume less than 300 kWh pay 4.5 % of the minimum salary. All the households are assumed to be low consumers of electricity as the mean consumption of electricity is 185 kWh/month. (Appendix 6) The minimum salary is $ 100/month, which means a cost for each household of $ 4.5. Every household has a mean production of waste of 158 kg per month which leads to the tipping fee of $ 28.4/tonne organic waste in Ecuador. The same price for compost is used as in Belgium. The plant in Belgium can sell the compost for $ 13 /tonne compost and 30 % of the mass put into the plant is returned as compost. All these calculations can be studied further in Appendix 9.

If one regards the payback time if the Dranco plant was built to provide Guasmo with biogas the undiscounted value would be 26.4 years and for the discounted, which means the interest rate of return is taken into account, the payback time was impossible to calculate as it is very long. The payback time for the Valorga reactor applied for Guasmo was 32.6 years. The payback time is based on the unsubsidized gas price which is $ 0.05/kWh. The payback time for the doubled gas price is 13 years for the Dranco process and 15.6 years for the Valorga process. The calculations can be seen in Appendix 9.

To make the biogas usable and easier to distribute, the gas needs to be upgraded. This means an additional cost for the production of biogas, which is about $ 0.02 /kWh. This cost is for a process that can upgrade 200-300 Nm^3 biogas/h to natural gas quality, close to 100 % methane. This makes the total production cost for producing upgraded biogas between $ 0.19-0.21 depending on the process of production. If we compare these values of production cost with the present price of LPG, which is $ 0.05/kWh excluding and $ 0.008/kWh including governmental subsidies, we conclude that the production cost for upgraded biogas is about 3-4 times higher than the present unsubsidized LPG price, and 24-26 times higher than the subsidized LPG price. This means that if a normal family in Guasmo today spends $ 2.7 (see Appendix 4) on LPG every month they would have to pay $ 57-70 for biogas every month.

[68] Mosquera G., Interview 2006-11-05

Biogas therefore has no possibility to compete with LPG presently, but if the government takes away the subsidies and the oil price rises in the future biogas is an alternative.

There are two more things that should be noted about the financial calculations; the first thing is that the price for energy and especially fossil fuels might increase more than the inflation rate in the future. This would lead to a shorter payback time. The second thing is the tipping fees. This fee is in other countries the largest revenue for the biogas plant. In this example the revenues from gas and tipping is equal. This might signify that the tipping fee is a bit low in the calculations or could be higher in the future. These things might lead to that investing in a biogas plant actually can be a prosperous business in the long run.

3.6 Discussion of Biogas Investigation

3.6.1 Can biogas compete with LPG today?

Presently there is unfortunately not a large scale biogas production system that can supply a sufficient volume of gas to a price that can compete with the LPG price of today in Guasmo. Even if the government of Ecuador took away the subsidies the LPG price would be too low for biogas to compete, see the passage on economy below for more info on this. For the economically sensitive inhabitants of Guasmo biogas sold instead of LPG therefore is no option. But selling the gas produced from a plant directly to customers in Guasmo at market prices is not the only way to distribute biogas, and economical factors are not the only or the most important reasons to implement biogas production. It has to be remembered that it is a mean of handling solid organic waste in a more sustainable way plus that it makes the nation less dependent on the importation of oil. Reasons that weigh heavily when considering future high oil prices that are maybe double or triple the oil prices of today in a ten year period. Even if it presently not is possible to implement a large scale biogas plant in Guasmo without some kind of extra financial support there still are several good arguments to implement it in Guayaquil.

3.6.2 The Best Biogas Production System for Guasmo or Guayaquil

If one solemnly considers the amount of produced energy from the Brecht and Tilburg plants and the cost for producing this energy the Dranco plant in Brecht with an annual production of 7.26 GWh and a production cost of $ 0.17/kWh is the best. The 7.26 GWh can cover 6.5 % of the gas consumption in Guasmo and is closest to the theoretically calculated maximum annual production of biogas for the area which is 13.9 GWh. But even if a Dranco plant has the lowest production cost of biogas and has the highest production it is not certain this is the best choice of biogas reactor. For instance the Valorga reactor has a lower temperature during the production and therefore consumes less energy for heating the process. This can mean that the net production of energy from this reactor actually is higher than from the Dranco. Another motive for choosing a Valorga reactor is that it is designed for a TS concentration of 20-35 % and the TS concentration in the solid organic waste from Guasmo is 24 %, a concentration well suited for this kind of plant. The optimal TS concentration for Dranco processes was not found but is believed to be about the same as the two processes are similar. When studying material from the OWS homepage[69] it has become apparent that also the Dranco processes are able to run at mesophilic temperatures but it did not say anything about the rate of production if the process was run at this temperature. It would be interesting to investigate at what temperature the best net energy production is achieved.

[69] Organic waste systems, OWS, 2006

Both of the processes can be run with grey waste and it is an interesting question to investigate what would be the most beneficial way for Guasmo and Guayaquil to handle their waste if biogas was to be extracted; collecting source separated organic solid waste or collecting grey waste and treating a mixed stream of waste. If a plant to treat grey waste was implemented it might be more economical because the municipality would not have to treat organic and inorganic solid waste at different spots. Yet another interesting thing to investigate is whether or not it is possible to incorporate the human excretes from the many toilets with septic tanks in the area.[70] This might increase the production rate of biogas and one would not have to treat the human excretes somewhere else and it can therefore be beneficial for both municipal economy and biogas production. Finally one last interesting thing to investigate could be to see if it was possible to implement an integrated biogas-landfill gas treatment plant like the Dranco plant in Salzburg, Austria, at the site of the of the present landfill in Guayaquil "Las Iguanas".[71] By doing so one could also utilize the gas produced by the landfill which today only is burned.

3.6.3 Waste Collection System

If an implemented biogas reactor was to run on OFMSW an important condition for the reactor to work is that household's source separate their waste. From the questionnaire and the collection of organic solid waste which was conducted it is concluded that it can be done. A large gain with the anaerobic treatment process of pure OFMSW is that the compost can be put out on cultivated land. If the waste stream contains large amounts of inorganic material, the cost for pre-treatment will increase and the revenues for the sold compost will reduce. Even though the investigation was made only of a few households in Guasmo it shows that most of the people had enough knowledge and were positive to the suggestion of source separation. The collection of the organic waste was better than what the authors had expected.

It is however hard to make changes in peoples habits and getting people to source separate without giving any other incitements than that it is good for the environment. An obvious incitement would have been if the households directly could use the gas from their own organic waste, which would be the case if they had a small scale reactor for their home only. Then the quality and amount of waste directly kick back on the biogas production. Unless the people connected to the biogas plant have a direct benefit from the biogas plant it might be hard to implement source separation. The problem would have been easier to solve if the biogas plant was a more economical way to produce cooking gas than the present system. Then the households could be enticed by lower prices. One solution could however be to lower the waste collection fees for those who source separated their waste.

3.6.4 Distribution System

There are always problems related to changes in a system and this is no exception. A big problem that needs to be solved to make an implementation of a biogas reactor possible is the problem of distributing the biogas to the users. The present system is based on lorries transporting the tank of LPG to each household. This is a dynamic system that could work for distributing the biogas as well if it was filled on the tanks instead of LPG. The problem is that the tanks can't handle the high pressure that is required to push in the same amount of energy in the tank as before. If upgraded biogas was to be used the tank can only contain a third of the former energy content with the same pressure. This means that the transportations by truck would be tripled and it would also mean more work for every single household. This is bad because the largest environmental gains would be achieved by using biogas instead of or

[70] INEC, Instituto National de Estadísticas y Censos, Guayaquil, 2001
[71] Organic waste systems, OWS, 2006

mixed with LPG for cooking in houses. This is also the only way international transports of oil and independence of oil can be achieved. One alternative could be to start using new tanks that are either bigger or able to stand a higher pressure.

The second and probably best solution could be to sell the biogas to the Machala power station which produces electricity for the Guayas region. The power station uses natural gas, almost pure methane, from fossil deposits outside the coast of Ecuador. The biogas could be transported in a gas pipe to the power station where the biogas could be used instead of the fossil natural gas, which would mean more environmentally friendly produced electricity. This would also mean lower investment costs for a biogas plant as the biogas would only have to be dried and cleaned but not upgraded.

3.6.5 Economy

A biogas plant is not an economically good investment in the present waste or energy system in Guasmo without extra financial aid. The price for the produced biogas needs to be three times the present unsubsidized price for LPG to make the plant break even annually and one has to remember that Guasmo is a poor area and raised costs might lead to an economical disaster for the households. It is therefore unsuitable to make any increases in fees or costs for cooking gas in the area of Guasmo. The unsubsidized LPG price is the price connected to the international oil market and would be the highest price that the biogas could be sold for. The payback time for the plant with that gas price would be 26 years, six years longer than the economical life time. Another problem is that the government has large subsidies on cooking gas for the households. The households only pay 1/6 of the real gas price and the government pays the rest. However the subsidies are a big problem for the government and a big cost.

The only chance for a profitable biogas plant is an increased oil price or increased fees for tipping the waste. The diminishing oil resources might lead to a higher oil price in the near future and the government needs to solve the LPG subsidy problem before that so even if a biogas plant can not stand on it own legs today there are still very good incitements for implementing one in Guasmo or somewhere else in Guayaquil. Today 40 biogas plants could be constructed every year for the amount of money equal to the annual cost of LPG subsidies.

There is a chance for extra financial aid in the form of CERs from the clean development mechanism (CDM). The clean development mechanism is a part of the Kyoto protocol and through it projects in developing countries that contribute to the global reduction of CO_2 emissions can receive CERs by applying at the Executive Board. There are already several other projects in Ecuador which have received CERs, one of these is the Zámbiza Landfill Gas Project[72].

When discussing the issue of finance for these kinds of projects a number of actors that might be interested were thought upon. Primarily the stately owned company that has monopoly on importing oil and also imports LPG to Ecuador, Petroecuador, might be a suitable investor for a biogas plant. They have the knowledge and distribution system to sell the gas in the country and they might also be interested in starting a more self supplying energy system. Other actors can be the present operators of the landfill “Las Iguanas” and the company that collects the household waste in Guayaquil if they are not the same. The municipality of Guayaquil could also be an interested actor as implementation of biogas production will lead to a more sustainable development in the city.

[72] UNFCCC, CDM-Home, Feb 07

3.6.6 Environmental Benefits

The Municipality of Guayaquil has since the middle of the twentieth century opened their eyes to environmental problems. Yet another step in this direction would be to implement a biogas reactor. The waste would be treated with a better utilization of resources than in the present treatment system and will have many further benefits.

The first and most important benefit would be the reduction of carbon dioxide emissions from the combustion of fossil fuel. The biogas plant produces 7.26 GWh biogas and the size of the carbon dioxide reduction would therefore be equal to the absent combustion of 7.26 GWh LPG. A second benefit is that the emission of green house gas from the landfill also will be reduced. The waste is now put on a landfill in more or less anaerobic environments. The Municipality claim that gas and water from the waste is treated, but the waste is covered by a layer of sand and will most probably leach both gas and water. The released methane from the landfill has a green house effect 20 times stronger than carbon dioxide. The introduction of a biogas reactor would make the treatment of organic waste more controlled and it would create an economical incitement for collecting the gas. If the waste stream of organic substances would be separated the amount of waste that goes to the city landfill would reduce, the leakage of gas from the landfill would be lower and the residuals from the anaerobically degraded organic waste could be used in the agriculture as fertilizer.

Another positive effect with domestic production of biogas is that the need for transportation will be reduced. The oil, now extracted in Ecuador and sold to other countries where it is refined and bought back again as LPG, leads to long transportations. If biogas is used in the Ecuadorian homes instead of the LPG, at least some part of the international oil imports can be excluded. But this would only be the case if biogas was filled or mixed with LPG in the tanks presently used in the Ecuadorian homes.

The transportation from the domestic natural gas deposits to shore is done by boat. If biogas was transported to the Machala power plant and replaced some of the natural gas there. It would lead to reduced boat transportation which will lead to reduced use of fossil fuels and lower emissions of carbon dioxides as well. This reduction of emissions will probably be smaller than the reduction of emissions from international transports though and depends on how the biogas is transported to Machala, by pipe or by truck.

When discussing transportation it should also be said that today Guayaquil has large traffic congestion and air pollution problems. This makes it important to minimize transportations through the city and today the collected garbage of Guasmo is transported from the southern most part of the city almost all the way to the northern most part of the city. Implementing a biogas plant in the south of the city would reduce transports and air pollution from it.

3.6.7 Validity of the Results

When discussing the validity of the results it is first important to evaluate whether the results from the investigation are representative for the whole area of Guasmo. It is important to say that the collection of solid organic waste just like the Survey Study of Guasmo only was conducted in one sector of Guasmo and that Guasmo comprises of about 30 of these sectors. So to be realistic the values are only valid in just this sector. Both the collection of organic solid waste and the survey study could have been conducted in more sectors but this was not possible due to lack of time and the security situation. It was not safe to conduct the investigations in other areas of Guasmo than in the close proximity of Fundación Huancavilca. The amount, quality and the success of source separation is based on data from the collected waste of 10 households. Other measured parameters like the LPG use, number of inhabitants in the household, attitude to biogas and source separation is based on about 100 households, therefore it might have been relevant to collect solid organic waste from more households but that was really not possible for logistical reasons.

Table 5. Mean values used in this chapter.

Parameter	Water contents OFMSW	Ash contents OFMSW	Mass of OFMSW (kg/family and day)
Mean	76 %	0.7 %	1.2*
Standard Deviation	7 %	0.4 %	0.7
No. of samples	49	18	49

* = 5 highest and lowest values have been excluded

The calculated mean production of solid organic waste from one family during one day in Guasmo is thought to be realistic even though the standard deviation is rather high. It is based on that the mean number of members in a family is 6 but when collecting few samples like in this investigation it would have been better to use the exact number of members in each family. This was done but the information was lost and only the number of members in 6 of the families was recovered. The mean production of organic solid waste per family and day based on the exact number of family members was 1.6 kg/family and day. The difference is not big but it signifies that the true mean can be somewhat higher. See Appendix 3 for more information on this. According to Las Iguanas the normal household produces 5.3 kg waste every day, if one compares this to 1.2 kg/day it can be seen that the organic fraction constitutes 23 % of the total waste production from one family which does not seem unreasonably large. However it is a problem that seasonal variations of mass and compositions of the solid organic waste might exist and have not been considered.

The water concentration in the solid organic waste samples is considered to be accurate and as can be seen in the table it has a small standard deviation as well. The ash concentration in the organic solid waste is however relatively uncertain with a high standard deviation. This is probably because it is based on relatively few values but it is off less importance as it is so small anyway and also only affects the calculated maximum production of biogas.

Probably the largest uncertainty in the whole biogas investigation is the determination of the organic waste quality. By this the mass of each of the components out of all the collected solid organic waste is intended, e.g. the mass of rice, bananas and melon out of the mass of all the collected solid organic waste. Subsequently the amount of fat, protein, hydrocarbon and fibres are of high uncertainty but it is not possible to present this as these samples have been considered to be one total mass and was not treated as individual samples. To investigate each sample like that would have been extremely time consuming. The composition of the solid organic waste samples was determined visually and not by means of weighing. There is also uncertainty because of the fact that almost all the collected material was composed of different kinds of peels and not by whole fruits and vegetables and these peels are not certain to contain the same composition of fat, proteins and hydrocarbons as the fruits and vegetables in the nutrient tables. The nutrient tables which were used did not say if the values they presented were based on the whole of the fruit or only the editable part of the fruit. However the only calculation affected by this is the maximum biogas production and not the productions from the Dranco and Valorga plants.

Lastly there are the calculations of the production cost for biogas and the payback time which needs to be commented upon. When it comes to the production cost of biogas the results are considered to be fairly certain but they are of course only pointers of the true production costs. The interest rate of return is based on common practice in the business world. It is set to 10 % which might be too high for these kinds of projects. But it is considered better to set it too high than too low. However the calculations are highly dependent on what the interest rate of return is set to. The other factors affecting the production costs is the capital investment cost, the tipping fee and the cost for labour, maintenance and administration. Annual costs for labour, maintenance and administration was set to one-twentieth of the capital investment cost; this equals about $ 500 000/year, which is probably high and a more precise value would have been desired. The tipping fee is based on current costs for waste disposal in Ecuador and is therefore considered to be correct. The capital investment costs are based on literature values made by consultants. However since the capital investment costs affect the result highly more and more up to date figures would be desired. The last things that can be investigated more is the price one can sell compost for in Ecuador and how much the municipality spends on the present waste treatment system. The price for compost is the only fact in the economical calculations. But all in all the approximation for the production cost of gas and payback time is thorough and in depth.

3.6.8 Margins of Error and Other Problems

This study was greatly limited by time, which had a big affect on what parameters that could be investigated. Yet another limitation of the study was that only a literature study of different biogas reactors was conducted. Operational personnel could have been contacted and more detailed data on production rates, cost of running and investment costs could have been acquired. Another thing that may have led to errors in the results is the equipment used in the gathering of data. Scales and oven used in the investigation could have been imprecise. Still another margin of error is that when calculating production of biogas for reactors appropriate for Guasmo the same biogas production rate as for the reactors in Belgium and the Netherlands was used. This means that composition of waste is assumed to be the same in Ecuador, Belgium and the Netherlands, which it of course is not. When comparing the maximum annual biogas production with the annual production from the two plants, it can however be noted that they are not unreasonably high.

3.7 Future Prospects

The constructing of a biogas plant in Guayaquil is a step towards reducing carbon dioxide emissions. The problem is that for a poor area like Guasmo it is hard to formulate a biogas project that the area would benefit from economically, which is the most important argument in poor areas. Therefore it might be a better suggestion to let the biogas plant have a middle or high class area as collection area and only have pure socioeconomic projects for Guasmo, not environmental ones. It is a classic dilemma if one tries to combine environmental and socioeconomic projects in poor areas as there almost always are conflicts between these two issues.

Guayaquil has good conditions for producing biogas, there are resources in unused organic material that today only is put on a landfill and it is theoretically possible to source separate the organic material as well. There are agricultural areas close by that could use the produced compost and there are good alternatives for using the produced biogas; both mixed with LPG for cooking at home or mixed with natural gas in the Machala factory for electricity production. There would also be environmental gains in reduced long way transports of LPG. The local energy production would also be an advantage in a future energy crisis.

If a biogas plant was to be invested in, a number of possible investors were thought upon while writing this study. First of all Petroecuador might have an interest in being an investor because they are the present suppliers of LPG to the Ecuadorian market and it would therefore be logical if they also started a production of biogas that could be mixed with LPG and transported to the domestic distributors like Duragas/Repsol the same way LPG is today. Secondly the company that handles waste collection and runs “Las Iguanas” in Guayaquil might be interested in being an investor in a biogas plant because it would decrease the amount of waste put on the landfill and it would not fill up as quickly. But also because biogas production might be a way of making more money out of waste treatment if they can sell the gas and the compost plus charge a tipping fee. Lastly it might also be possible to finance the project by the Clean Development Mechanism which is a part of the Kyoto protocol because a biogas plant that produces biogas to be used instead of LPG for cooking or made electricity of would reduce carbon dioxide emissions from Ecuador.

To make a more thorough investigation of possible plants for biogas production and better economical predictions of the costs for this could be the subject of another master thesis for environmental engineers from Lund or student with similar educations in Guayaquil. But the thesis should have more of a focus on investing the present waste handling system and the cost of it. Or another point of focus could be on contacting different suppliers of biogas plants and investigating the capital investment cost and maintenance of different plants in more detail. A third point of focus could be to investigate if a biogas plant that handles grey waste or source separated organic waste would be best for Guayaquil.

3.8 Resumen: Investigación de posibilidades de biogás.

Ecuador es, entre los países en Sur América un gran consumidor de gas LPG, actualmente importa el 75 % del gas para el consumo interno. LPG corresponde al consumo de energía más representativo en Guasmo (ver detalles en capitulo 2). El LPG podría ser reemplazado por biogás, con las ventajas de no incrementar el efecto invernadero y por tanto es una fuente de energía más ambiental. El biogás es un gas producido por reacciones de descomposición de basuras en un reactor para materia orgánica.

Una investigación sobre la basura orgánica fue realizada en Guasmo, en el mismo sector en donde se desarrollo el cuestionario de preguntas. Para el análisis de los desechos orgánicos, se pidió a 10 familias que recolectasen su basura orgánica en un recipiente especial y durante cinco días. La basura fue examinada con respecto a peso, y concentración de agua y carbón. Los resultados fueron usados para elegir el proceso de descomposición apropiado y para poder calcular cual sería la posible producción de biogás de una familia típica del Guasmo. La investigación mostró que la basura tiene un contenido principalmente de cáscaras de frutas, verduras y arroz y que tiene una concentración de agua del 76 % y una concentración de carbón del 23 %. Cada familia producen alrededor de 1.2 Kg. de basura orgánica diaria.

Dos procesos de descomposición adecuados para la calidad de la basura encontrada y aptos para el clima de Guayaquil fueron investigados: uno el llamado Valorga y otro el llamado Dranco, (ver mayor detalle figura 14). El mejor procesador para las circunstancias dadas, fue el procesador Dranco. Este procesador trabaja con una temperatura de entre 50 – 58 °C y produce entre100 – 120 Nm^3 de biogás por tonelada de basura con una concentración de metano de entre el 50 y el 60 %. Una planta de biogás con un procesador Dranco fue construida en Brecht, Países Bajos en 1992 con un costo de $ 4.7 millones. Se calcula que el costo de construcción de una planta similar para Guayaquil construida hoy día sería de 10 millones de dólares –$USD. Este tipo de planta puede producir 7.26 GWh/año, suficientes para satisfacer al 6.5 % de los hogares en Guasmo con biogás apto para la cocción de alimentos. El precio por el biogás seria de $ 0.19/kWh, 4 veces mayor que el precio por LPG sin subsidios que es de $USD 0.05/kWh y 24 veces mayor que el precio actual de $USD 0.008/kWh. El pago de la planta culminaría después de 26 años, y se calcula un interés nominal del 10 %, y un precio del biogás de $ 0.05/kWh.

Desde un punto de vista económico la inversión en una planta de biogás no es buena; sin embargo existen otros aspectos positivos a considerar. El efecto ambiental es grande pues el biogás puede sustituir al LPG y las cargas ambientales del relleno sanitario en por ejemplo la estación de basuras "Las Iguanas" en Guayaquil disminuirían, y por tanto las emisiones de metano de los desechos serían menores. Metano es un gas expulsado en rellenos sanitarios y que afecta negativamente al clima. La importación de LPG disminuiría al igual que el transporte del mismo y la economía nacional no sería tan sensible al precio internacional del petróleo. La basura descompuesta puede usarse además como fertilizante para la agricultura. La construcción de una planta para producir biogás puede ser una buena estrategia para desmantelar el sistema de subsidios de LPG, el cual no es óptimo. Un requisito indispensable para la producción del biogás, es el establecimiento de un sistema de selección de basura orgánica doméstica; esto demanda sin embargo incentivos e inversiones. Estas podrían proceder haciendo un mejor uso por los $ 400 millones que el Gobierno esta pagando cada año para los subsidios. Los hogares en areas con ingreso bajo que estén dispuestos a separar la basura en dos lugares deberían poder conservar los subsidios; pero los hogares en areas de alta renta deberían perder este derecho. Las condiciones para la construcción de una planta de este tipo, van de hecho a cambiar, debido al constante incremento en los precios del petróleo; mientras que el precio del biogás permanecerá muy seguramente sin modificaciones. Los expertos creen que el precio del petróleo va a estar dos veces más alto en pocos años.

Los escritores creen finalmente, que la empresa petrolera del estado, Petroecuador puede ser un inversionista apropiado para una planta de biogás. Ellos tendrían buenas posibilidades para distribuir el biogás, tienen además buenos conocimientos sobre el manejo de gas y quizás con ayuda financiera del Gobierno o inversionistas extranjeros a través de una forma de proyecto, *CDM- clean development mechanism* * podría representar para ellos una inversión lucrativa. La ejecución de la construcción de la planta de biogás requiere por supuesto mayor investigación, pues por un lado la producción y composición de la basura organica debe ser analizada más profundamente; los resultados y conclusiones de este estudio han sido basados en un estudio de campo hecho en un solo sector y solamente durante cinco dias. Por otro lado el precio y producción de la planta de biogás en si misma, necesita mayor investigación pues la valoración de costos fue basada en la información y conocimiento tenida de plantas de biogás europeas construidas hace varios años.

* *CDM-clean development mechanism.* Mecanismo que busca el desarrollo de proyectos con resultados beneficiosos para el medio ambiente. Este tipo de mecanismo ha sido una de las consecuencias del protocolo de Kyoto; en donde se permite que países industrializados inviertan en proyectos en países en vías de desarrollo; bajo las normativas de una comisión comprometida primordialmente en la reducción del efecto invernadero.

4 Investigation of Solar Powered Air Conditioning

4.1 Introduction

In this chapter, the possible operation and use of a solar panel/absorption chiller -system, later referred to as sp/abc-system will be investigated. This system could be used for residential room cooling applications for the houses in Guasmo. This is important because the system could improve indoor climate conditions while reducing CO_2 emissions, increasing energy security and providing sustainable development to tropical urban areas.

Already today, cooling and air conditioning use more energy than heating in a global perspective. This situation will continue to be so, because the population growth in the tropical areas of the world is larger than in other regions. As the socioeconomic situation in many of these areas including Ecuador is slowly improving, electricity consumption will continue to increase because of an increase in air conditioning devices. Therefore the development of air conditioning devices and cooling systems that consumes less electricity than conventional ones is fundamental. It is also important to design a system that will be technically and financially affordable for the majority of the population including the low-income inhabitants of Guasmo.

Many low-income households are potential future air conditioning owners when they get a better financial situation according to *Adamson and Åberg, 1993*. They also state that many power shortages in developing countries depend on excessive use of electric air conditioning devices. It would be very important that the solar absorption cooling technologies become affordable in the next years. The whole population, including low-income users as well as the environment would greatly benefit. Electricity costs are rising worldwide and the electric bill is a large portion of low-income family budgets.

4.2 Background

4.2.1 Climate in Guasmo

As said earlier in chapter 1.5.2 about Guayaquil, the climate is warm and humid. In the 'winter' period, from December to April, the temperature has a minimum daily mean of 23.6°C and a maximum of 31.6°C. The relative humidity is about 80 %. In the 'summer' the temperature is somewhat lower and the minimum daily mean is 20.7°C and the maximum mean is 29.5°C. The relative humidity is generally 5 percentage units lower.[73] Below in Figure 25 is a temperature graph for Guayaquil and this is the outdoor temperature which will be used later in the simulations of the indoor climate.

[73] Patricio Riviero Murillo, 1999

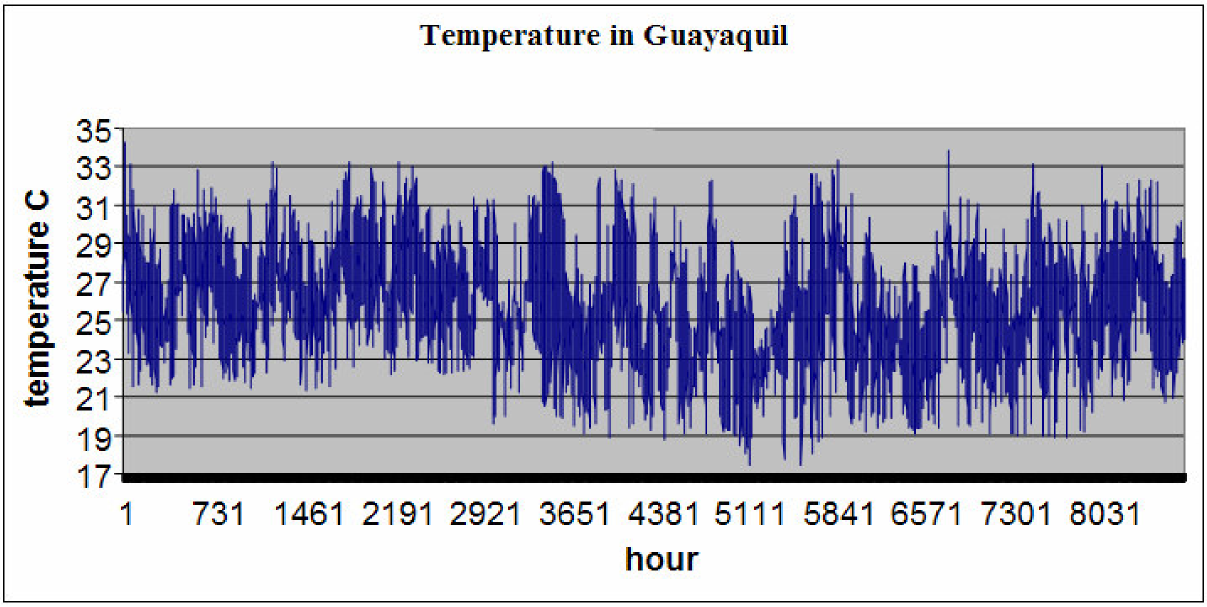

Figure 25. Yearly temperature of Guayaquil according to Meteonorm reference year. The scale is divided in to 730 hour periods, which is equal to one month.

Other important information which later will be needed for the simulations is the annual solar radiation. The theoretical maximum effect from the sun at a right angle to the surface of the earth can be calculated to 1370 W/m^2 and is called the solar constant. Some of the solar radiation is however reflected or absorbed in particles in the atmosphere and emitted back to space without reaching the earth surface. The amount of energy that reaches the ground is depending on the amount of particles in the atmosphere. The reflection from dust can be around 14 % while clouds can reflect between 30-60 % of the solar radiation. This means that the maximum effect of sunlight that reaches the ground is about 1000 W/m^2. More solar energy is accessible around the equator than in the northern and southern hemisphere due to the fact that the incident angle is closer to 90 degrees and that the sun is closer to the equator than the poles.[83] The solar radiation for Guayaquil is displayed in Figure 26 below.

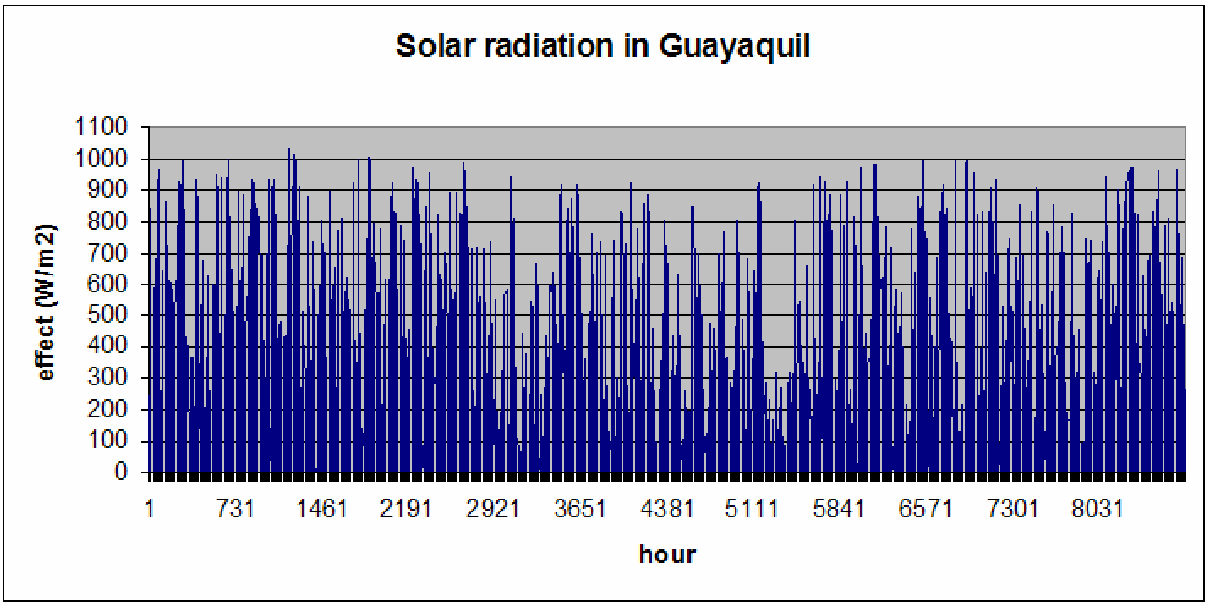

Figure 26. Yearly solar radiation in Guayaquil according to Meteonorm reference year. The scale is divided in to 730 hour periods, which is equal to one month.

Normally the solar radiation is measured with a solarimeter, but no such data is available for Guayaquil. The solar radiation has, however, been calculated with the computer program Meteonorm. This program uses solar geometry and climate data like temperature and humidity from the investigated place to estimate the direct and diffuse solar radiation. Meteonorm then simulates the hourly variation in solar radiation for a reference year. This theoretically calculated solar radiation may differ from real values, especially the partition between the direct and diffuse components, since clouds and particles in the air may vary locally. This needs to be taken under consideration when using data from this program.[74]

4.2.2 Present Indoor Climate in the Houses of Guasmo

In the Survey of Guasmo, it was shown that 90 % of the participating households were not satisfied with their indoor temperature during the winter period December to April. During the rest of the year 30 % of the households were unsatisfied with the indoor temperature. In all of the houses 40 % were unsatisfied with indoor ventilation. In the survey study it was also shown that presently only 5 % of the investigated houses in Guasmo have an air-conditioner, but 80 % of the households want to have one in the future.

4.3 Method of Solar Powered Air Conditioning Investigation

The investigation of the sp/abc-system was performed through theoretical calculations in Sweden but data was gathered in Ecuador to make the calculations as realistic as possible. Data about the living situation and the construction of the houses in Guasmo were retrieved from the *Survey of Guasmo* and from statistical information from INEC.[75] Some of the costs and performance data of the solar panel was received from TechnoSol a company located in Quito which also has representation in Guayaquil. The data for the absorption chiller was received from ECONICsystems smart cooling solutions, an Austrian company located in Vienna-Airport.[76]

This investigation was divided into three major parts, calculation of the solar system effect, calculation the absorption chiller effect and simulation of the indoor climate when applying the cooling effect from the absorption chiller. The two first were calculated and the indoor climate was simulated with a computer program called DEROB-LTH.

The solar panel calculations were done to calculate the energy that can be retrieved from the solar system. Meteorological data like air temperature and solar radiation as well as data from the solar panel were used. But because it was not possible to get all necessary information from TechnoSol for the solar panel, data from a similar solar panel from the Swedish company Solarit AB was also used. The solar radiation for every hour of a whole year was divided in three types of radiation, ground, diffuse and beam radiation. From information about the location of the panel and the three different radiations a combined total solar radiation that hits the solar panel could be calculated. The product information for the solar panel was used to calculate its efficiency. Losses from the solar panel and the tank were calculated and then subtracted from the radiation to receive the solar panel output effect. For a more detailed description of the calculations see Appendix 10.

Secondly the absorption chiller calculations where done to estimate the effect produced by the solar panel/absorption chiller-system. The absorption chiller is still under development which means that it has not been tested yet. Theoretical power and COP (coefficient of performance)

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[74] Meteonorm 4.0
[75] INEC, Instituto National de Estadísticas y Censos, Guayaquil, 2001
[76] Jendretzki D., Interview 2006-11-03

data was therefore provided by ECONICsystems. The theoretical data belongs to a 2 kW module using aAa (advanced Ammonia absorption) technology. With this technology the unit is very flexible and can operate at various different water temperatures. By knowing the water temperatures of the three cycles (heating, cooling and back cooling) the cooling effect from the solar cooling system can be calculated. Two regulations or methods of using the absorption chiller were calculated. One used the same mean effect all year round and the other was adapted to the intensity of the sun.

ECONICsystems published their COP data in a diagram at a constant outdoor temperature of 35°C, a powering temperature from the solar panel between 80-150°C and a cooling temperature between 5-20°C. The COP is not fixed. It varies depending on the temperatures of operation and on the outdoor temperature. Carnot cooling factors, factors without the losses in the system, were calculated for the hourly values of the climatic file for the whole of the year. These Carnot cooling factors were compared and adjusted to the theoretical COP for the ECONICsystems absorption chiller. A long vector of 8760 cooling factors was received from the as many outdoor temperatures. Every cooling factor (COP) was multiplied with the corresponding effect out from the solar system ($P_{solarsystem}$) and a mean cooling effect from the absorption chiller was received ($P_{cooling}$). This mean effect from the absorption chiller was then concentrated over only 8 hours daily with two different types of effect, one low effect during the cold period of the year and one higher effect during the hot period. For a more thorough explanation on how this was done see Appendix 10 and Appendix 14.

Finally a model of a standard Guasmo house was created in DEROB-LTH and three simulations were run with the model. One with no cooling that would be the reference case and then with the low continuous effect and lastly with the high regulated effect. To test the model further the standard Guasmo house was thereafter equipped with a ceiling and the three simulations were run again. This was done to test if the model reacted according to thermodynamic laws and to see if the cooling effect from the sp/abc-system would have a better effect. When the simulations were run DEROB was programmed to cool to the temperature of 26°C. This temperature was chosen because it was thought to be comfortable for a majority of people and to run the simulation a desired indoor temperature had to be set.

4.4 Delimitations

The time, the financial resources and the fact that the investigation was performed in Ecuador were limitations that put up the frames for this part of the project. These were the reasons why this study was only performed theoretically. Only simulated data for the temperature and the solar radiation were used for the simulations and it was not possible to go back to Ecuador to make tests on a standard house to see how well the simulated model correlated with the reality.

The time limitation has made it hard to investigate every aspect in the sp/abc-system thoroughly. The focus has been put on the absorption chiller process, the solar panel system and the simulation of the indoor climate. This was done because the functionality of these parts was believed to be most important in the sp/abc-system. The cooling tower for the absorption chiller, the cooling device and the pumps for the system were not investigated in depth. Further delimitations were that only two different regulation methods have been investigated for the sp/abc-system, one constant mean cooling effect and the other a higher effect used under a shorter period of time, only eight hours. The optimal direction of the solar panel has not been investigated either. It has only been set to face south even that it might be that a solar panel facing another direction would be more favourable in Guayaquil as it is situated close to the equator. The temperature in the solar panel tank has been calculated with simple programming in Excel. This was not found reliable enough to use for the calculation of the cooling effect and heat losses. A recommended mean value of 90°C has been set for the tank.

Another delimitation is that it is impossible to connect our Excel calculations and DEROB-LTH. We have programmed DEROB-LTH not to cool below 26°C. However this argument is not included in the programming in Excel. This means that Excel calculates a lower effect out from the tank and a lower temperature in the accumulator tank than it should be. If the cooling would stop also in Excel when the indoor temperature drops below 26°C there would be more energy left in the tank that could be used by the absorption chiller.

An economical comparison between a traditional air-conditioner and sp/abc-system has been made however only with the investigated components for the sp/abc-system. This was made to give a feeling about how the system would stand economically against the traditional air-conditioners.

4.5 Theory

A solar panel/absorption chiller system consists mainly of an absorption chiller with three closed water cycles. The first is a heating water cycle that brings hot water from the solar panel. The second cycle is a cooling water cycle that brings heat from the room and the third cycle is a back cooling cycle that dissipates the heat outside the house.

There are many different combinations of systems depending on the cooling effect and how it is meant to work. An example of a sp/abc-system can be seen in Figure 27.

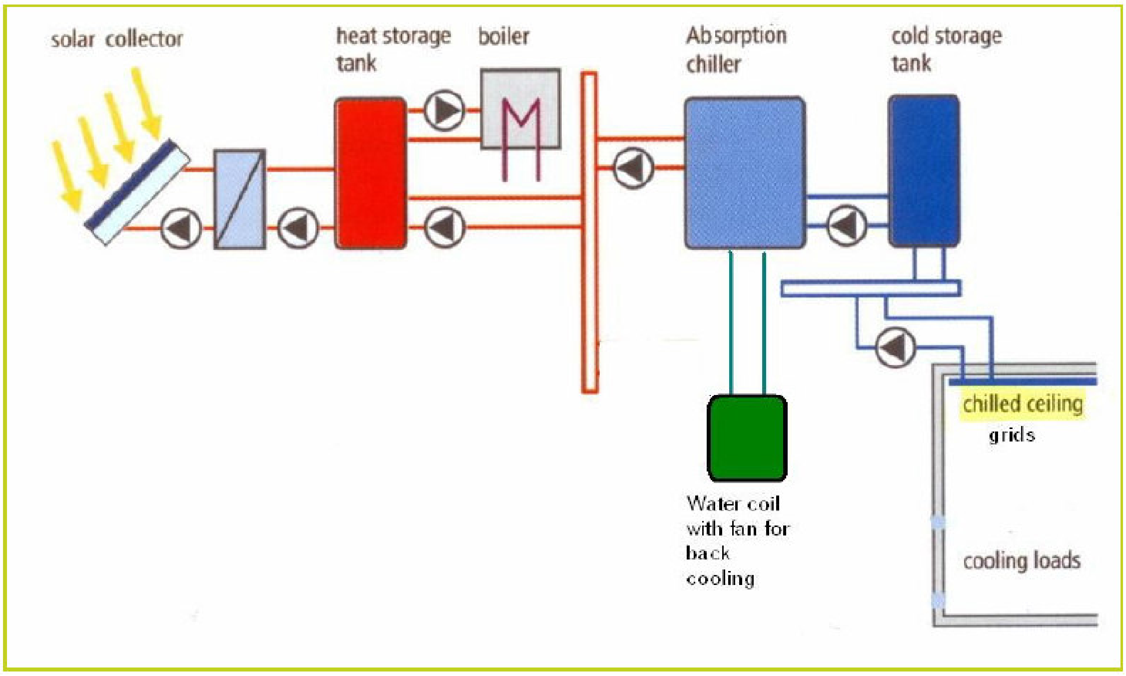


Figure 27. System scheme for a sp/abc-system.[77]

The system in the picture is an advanced system with high reliability. As can be seen in the picture the solar panel system contains of solar panel, heat storage tank and a boiler. The absorption chiller system comprises of absorption chiller, back cooling tower or water coil, cold storage tank and a cooling device and each of the systems are closed in the separated

[77] Technology update from ECONICsystems, November 2006

cycles. The cooling device in this case is a chilled ceiling. The following chapter will describe the theory behind the different parts of the absorption chiller system to understand how the system works.

4.5.1 Solar Panel System

The solar heating systems use sunlight to collect heat. The basic principle is that the solar panel absorbs the sun light and transforms the energy into heat which is stored in an accumulator tank. The heat can be used as hot water for sanitary purposes, space heating, warming the swimming pool or as in this case space cooling. The systems are basically composed of a solar panel and a storage tank. The systems can be divided into two different classifications depending on their function:

- Forced circulated systems that use an electric pump to pump the liquid in the system.
- Systems based on natural circulation from the density difference in the liquid.

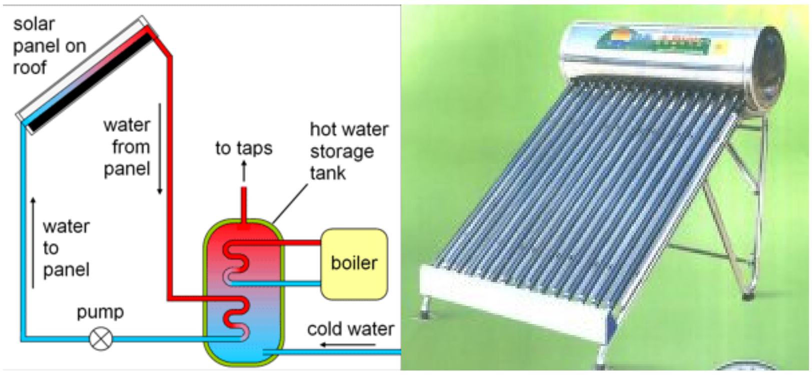


Figure 28. The two systems in order. First is the forced and the next is a self circulated system.[78 79]

4.5.2 Solar Panel

The solar panel is the collector of the solar radiation. The solar panel collects the short wave solar radiation and prevents the energy from getting reemitted as long wave heat radiation. The collected effect is depending on the panel area and the difference between the absorption and the emittance of the material. There are various types of solar panels depending on the applications and location where they are installed. All of them have a solar collector area, medium for collecting the solar energy and tubes for the medium. Most of the solar panels also have a protecting shield of glass or plastic that prevents heat losses. The higher temperature and demand of efficiency the solar panel has the more important is the thermal insulation. Figure 29 shows the components of a flat-plate solar panel which is one of the most frequently used.

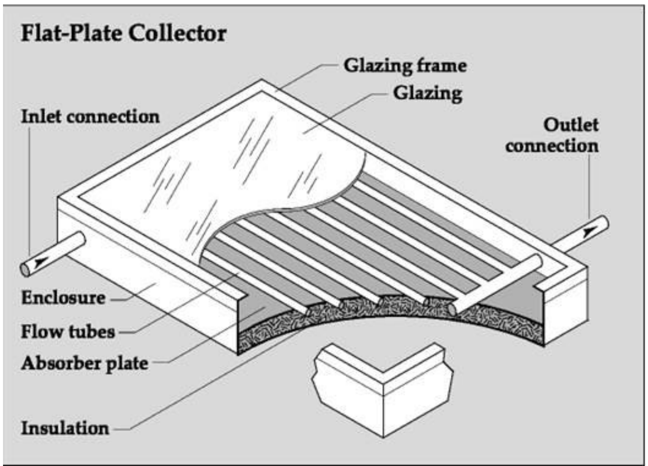


Figure 29. Components in a flat-plate collector.[80]

[78] Bitesize, 2007
[79] Solarit AB, 2006
[80] Nemmar.com, real estate from a-z, 2007-02-10

The collector area has a surface with high absorbency of the sunlight. The collector should also lead the heat easily to the medium. Metal collectors are frequently used in flat plate solar panels and vacuum panels due to their good heat transportation abilities. The surface can be treated, either painted black or anodized to increase absorbance and lower emittance. Good values for absorbance are 0.9-0.98 % and 0.08-0.15 % in emittance. The vacuum solar panel works with two different collector types depending on the system. The collector type depends on whether the connection with the solar circuit is wet or dry. The dry connection works with a metal collector where the heat is led to the pipe centre to vaporize a medium. The medium will condensate on a metal plate in the top of the pipe, where the heat is transferred to the solar circuit.[83] The wet connection uses a treated glass pipe that collects the sun light and the solar circuit medium circulates in the solar panel. The glass is treated with an Al-N/Al layer which has a very high absorbency for all wave lengths. These vacuum solar panels normally use a reflector to collect the sun rays to the glass pipe. The two principles can be seen in Figure 30. The reflector is normally a material with high reflection like a mirror.[81]

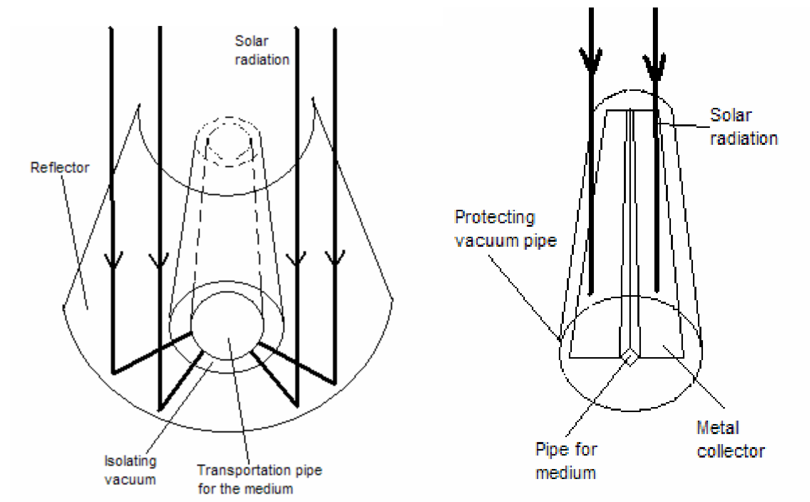


Figure 30. Vacuum solar panels, with reflector to the left and metal collector to the right.

Pipes in flat plate solar panels are normally made of copper and are connected closely to the collector material for a good heat transfer. The vacuum panels use the inner glass pipe or copper to transport the medium.[82] It is important that the material in the pipes is compatible with the medium used to prevent erosion.

Solar panels use many different mediums for the heat transport. The most frequently used thanks to its low cost is water. Water however has a short temperature span in the liquid phase compared to e.g. oil or glycol, which causes problems in cold climates and in high temperature systems. In cold climates the water can be diluted with glycol to prevent freezing. In optimized systems temperatures over 100°C are not unusual and the solar panel can be damaged if the water is boiling in the panel. This can be prevented by a higher pressure in the pipes or by using another medium like oil with a higher boiling point or a gas like air.[83]

The efficiency of the solar panel is the difference between the solar radiation that hits the solar panel and the energy that can be retrieved from the panel. The efficiency is depending on the material in the solar panel but also on the working temperature for the solar panel. The

[81] Solarit AB, 2006
[82] Solarit AB, 2006
[83] Andrén L., 2001

working temperature is the mean of the temperature in to the solar panel and the temperature out of the panel.

One of the major differences between different solar panel systems is the heat loss which has a great impact for the efficiency factor. The solar panels loose energy like all hot systems because of convection, conduction and radiation. The radiation losses can be reduced by low emittance in the collector material. The convection and conductivity are depending on the temperature and the material in contact with the collector. The material in contact with the flat plate panel is air. The vacuum solar panel contains vacuum and therefore has a very low or no conductivity. The conductivity for air is also low which makes it low for the flat plate solar panels as well. The convection is very depending on the air movement close to the collector. Both the flat plate solar panel and the vacuum panel are protected by a highly transparent glass. They are therefore protected from wind but the flat plate solar panel has an internal circulation that causes a convective heat loss. Since the vacuum solar panel lack a medium it is protected from convective heat losses. This is why the vacuum solar panel has a higher efficiency and can produce heat even though the surrounding temperature is low.

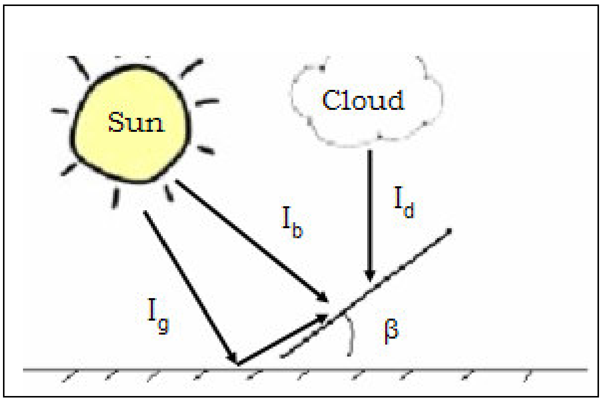


Figure 31. Different solar radiations.

The solar radiation that can be captured by a solar panel is divided into three parts, direct or beam sunlight (I_b), diffuse sunlight (I_d) and ground reflection (I_g). They all differ depending on the tilting angle of the solar panel (β). This can be seen in the Figure 31.

All of the radiations are added up to the total radiation (I_{tot}) that hit the solar panel. This is described in the equation below.

$$I_{tot} = I_g + I_b + I_d$$

The possible energy collected by the solar panel can be calculated with information on panel area, location, tilting angle, direction the panel is facing and the efficiency for the solar panel. This can be studied further in Appendix 10.

4.5.3 Solar Panel Circuit

Important for a solar system is the transportation of the energy to where the heat is needed. An electric pump is used in larger systems or in small systems in colder climates to transport the medium. The pump makes it possible to control the system and the tank can be placed anywhere in the system. Smaller systems in hot climates can rely on self circulation caused by the density difference between hot and cold fluids. This gives rise to a lower pressure difference and a lower flow compared to the pumped system. The tank has to be placed above the solar panel since the panel is the warm source. Cold fluid from the tank will sink down in to the solar panel and at the same time push up the heated fluid. When the solar radiation stops the circulation will automatically stop and the coldest water will be trapped in the solar panel preventing heat losses to the cold surrounding. The pumped system requires a more complex regulation system. A forced system can be seen in Figure 28. The most efficient solar panel system available is the self circulating system. The tank is placed above the solar panel as can be seen in Figure 32.[84]

The solar system works between very variable temperatures. This leads to volume changes of the medium in the tubes, due to the expansion of materials when heated. To avoid cracks and explosion of the tubes, an expansion tank is added to the system that can regulate the pressure differences.[85] The self circulating systems have a vent on the tank where steam can leave the tank if the pressure gets to high.[86]

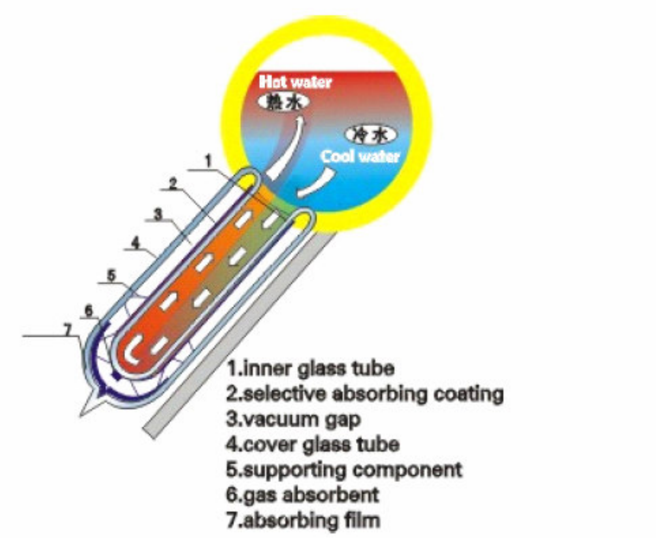


Figure 32. Self circulating system with vacuum solar panel.[87]

4.5.4 Heat Exchangers

A heat exchanger is used to transport heat from one medium to another. Heat exchangers normally work with two separated mediums divided by a thin wall and energy is transported from the hot to the cold medium. The heat exchangers are a very important part in the absorption chiller process and it uses about eight heat exchangers of different types to produce a cooling effect. The different techniques and types will be discussed below.

Heat transportation (P) in the heat exchanger is called heat transfer and consists of a combination of the three heat transfer processes, convection, conduction and radiation. The radiation in the heat exchangers in the absorption chiller process is very much lower than the other heat transfer processes. It is therefore excluded in the following calculation. The area (A) is the heat exchanger in contact with the medium and driving force is the temperature (T) which can be seen in the equations below.

Convection

$$P = h \cdot A \cdot (T_{wall} - T_{fluid})$$

Conduction

$$P = \lambda \cdot A \cdot \frac{(T_{wallIn} - T_{wallOut})}{dx}$$

The convection depends on the movements in the fluid. Great movements in the fluid give a high local convection coefficient (h) and a greater heat transfer. The conduction is depending

[84] Solarit AB, 2006
[85] Andrén L., 2001
[86] Solarit AB, 2006
[87] Solarit AB, 2006

on the thermal conductivity (λ) and the thickness (dx) of the separation wall between the mediums. When calculating the heat transfer the convection and the conduction can be combined in the following equation.

Equation 1. Heat exchanger calculation.

$$P = k \cdot A \cdot (T_H - T_L)$$

In this equation the impact of convection and conduction are included in the heat flow coefficient (k) as below. The index H and L signifies the high and the low temperature side.[88]

$$\frac{1}{k} = \frac{1}{h_H} + \frac{dx}{\lambda} + \frac{1}{h_L}$$

4.5.4.1 Heat Exchangers with Different Flow Directions

There are many types of heat exchangers and the most used ones are classified according to the flow direction. These groups are called counter flow, parallel flow, and cross flow heat exchangers. The two flows are separated by a thin wall. As the name reveals the different types are classified regarding to the direction of the flow on each side of the wall. This is important due to the fact that heat flow is quicker when the temperature difference is high. Figure 33 and Figure 34 show the temperature course for the parallel and counter flow exchangers which are the most common solutions.[88]

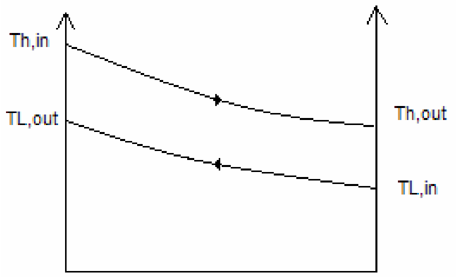


Figure 33. Temperature course for a counter flow heat exchanger.

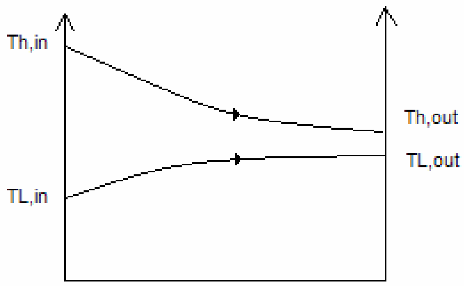


Figure 34. Temperature course for a parallel flow heat exchanger.

4.5.4.2 Different Heat Exchangers

Absorption chillers use different kinds of heat exchangers appropriate to their size and purpose. The counter and parallel heat exchangers are the most common ones and they can be seen in the system scheme in Figure 39, written as a quadratic box split in half by a diagonal line. The difference between the two types is that $T_{L,out}$ never can be higher than $T_{h,out}$ in the parallel heat exchanger but the heat transfer is quicker and requires a smaller heat exchanger area compared to the counter flow heat exchanger. The temperature $T_{L,out}$ can be higher than $T_{h,out}$ in the counter flow heat exchanger, but a larger heat exchanger is needed. The most common design is to connect the exchanger in tubes, where the hot medium flows around a tube with the cold medium. A more compact design is the plate heat exchanger. This is constructed of thin metal plates put together in layers. The surface is laminated to get a turbulent flow and a good heat transfer already at low fluid speed.

[88] Alvarez H., 2003

The mediums do not have to be fluids or gas all the way through the heat exchanger as in the Figure 33 and Figure 34. The medium can be evaporated or condensed during the heat transfer. The boiler and the condenser in the absorption chiller are examples of heat exchangers that work under these conditions. The temperature during condensation and evaporation is constant which has to be taken under consideration when designing the heat exchanger.[88]

Recuperated heat exchangers are another kind of heat exchanger that lacks the wall that separates the mediums and the two streams leave the exchanger mixed. All the energy from the hot stream will rapidly be transported to the colder medium without heat losses. The absorber in the absorption chiller process uses this method.

4.5.4.3 Cooling Devices

Another important application for the heat exchanger is in the cooling and in air conditioning of the indoor climate. Several different methods can be applied to lower the temperature and treat the air in the room. Some of these methods are called, cooling baffles, cooling panels/grids, fan-coils and induction cooling. The cooling baffles use flanges cooled by the water from the cooling source and air from indoor or outdoor pass the flanges. The air moves through the heat exchanger by natural force, as the cooled air sink through the device.

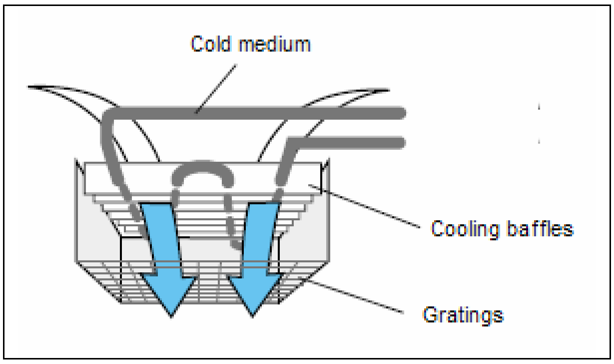
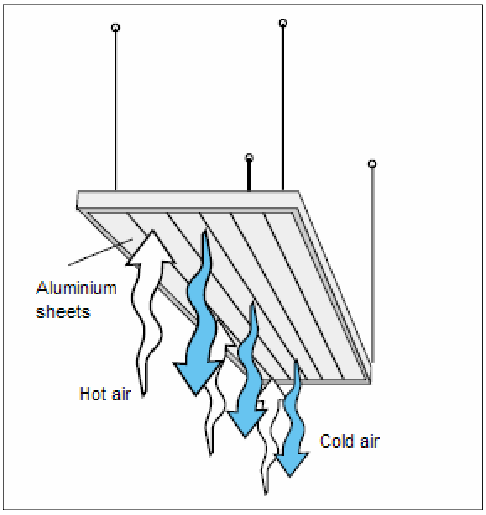


Figure 35. Cooling baffle system.[89]



Cooling panels or radiation coolers work in a similar way. Water passes through panels or grids that are placed in the ceiling. The heat from the room is transferred by radiation and transmission to the water. Natural convection occurs allowing for silent and virtually draft free operation. This solution allows for ‘high’ cold water temperatures of 15°C while still creating a comfortable cool feeling.

Figure 36. Chiller ceiling or radiant cooling panel.[89]

Fan-coils use a fan to push the warm indoor air through a cooling battery as can be seen in Figure 37. The water takes up energy from the air. The fan-coils allow a compact design for the same cooling effect. The fan can produce a higher air flow and more air can be treated in a smaller area. The drawback is that the cooling battery needs to have a lower temperature compared to the previous solution and that the fan requires electricity.

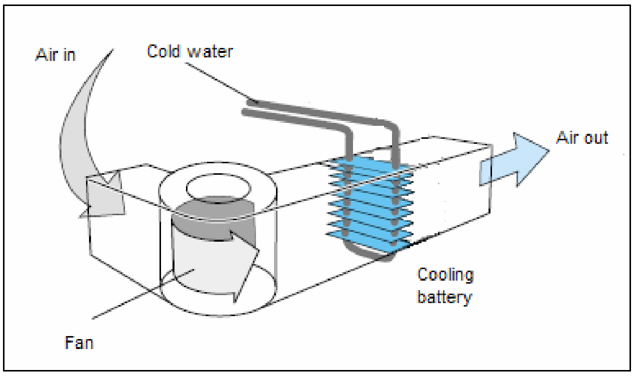


Figure 37. Fan-coil system..[89]

The induction system cools the indoor air by a cooling battery as well. The benefit with this system is that no fan is required. The cold space around the cooling battery produces a lower pressure and the air from the in and outside flows towards this zone of low pressure. The outdoor air is accelerated throw a nozzle and pulls by its higher speed the indoor air through the cooling battery as the figure shows.[89]

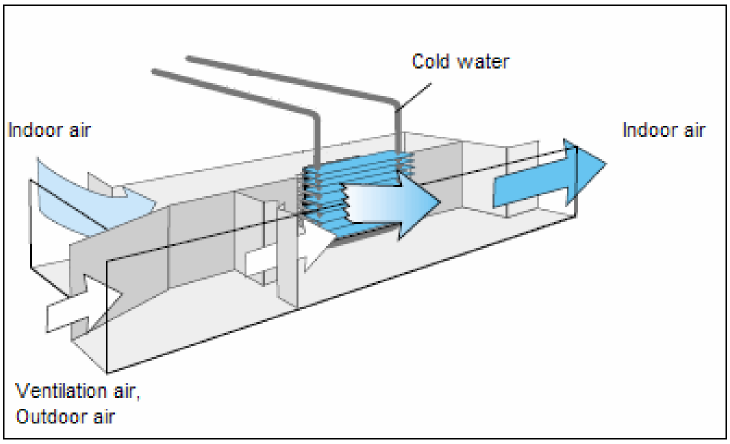


Figure 38. Induction cooling system.[89]

4.5.4.4 Efficiency of the Heat Exchanger

The heat exchangers need to be insulated in the outer wall to avoid heat losses. If no energy is assumed to vanish to the surroundings the reduced heat effect in the hot medium is just as high as the added heat effect in the cold medium. In reality the surrounding walls of the heat exchanger are not that well insulated that no energy is lost through the walls. It is also impossible to transfer all the heat from the hot medium to the cold medium, which means that the outgoing temperature of the cold medium is lower than the theoretical calculated value. This is referred to as the efficiency of the heat exchanger. According to *Wimmerstedt. R.,* the temperature out from the heat exchanger is normally 5°C warmer compared to the theoretical value.[90]

[89] Nilsson P E, 2001
[90] Wimmerstedt R., 2001

4.5.5 Absorption Chiller System

The absorption chiller is a French invention from the middle of the 19:th century.[90] Two Swedes from the Royal Institute of Technology (KTH), Stockholm, made the invention to a commercial product and the absorption chiller was soon used in Platen Munther refrigerators in many homes.[91] Today the absorption chiller is used as a replacement for traditional compressor coolers in air conditioning devices and refrigerators. The absorption chiller is a cooler or a reversed heat pump that transports heat from a cold medium to a hotter. To transport energy like this requires energy according to the second law of thermodynamics. Conventional cooling machines use electricity, while the absorption chiller can be powered by heat.[92] The absorption chiller can produce a cooling temperature between -60 and 20°C depending on the system.[93]

The absorption chiller works like other cooling processes with two pressure levels where the cooling medium is vaporized at a low temperature and a low pressure.[94] The big difference is that heat is used to separate the mixed absorbent and refrigerant to retrieve the refrigerant at a high pressure. The absorption chiller comprises of four important components, boiler, absorber, condenser and the generator. The system can be seen in Figure 39.

As for a Carnot process two of the components work with a high pressure and two with a low pressure. The condenser and the generator work with the higher pressure that can be received by an electrical pump or a hydrogen cycle. The pressure is lowered again through a vent.[95]

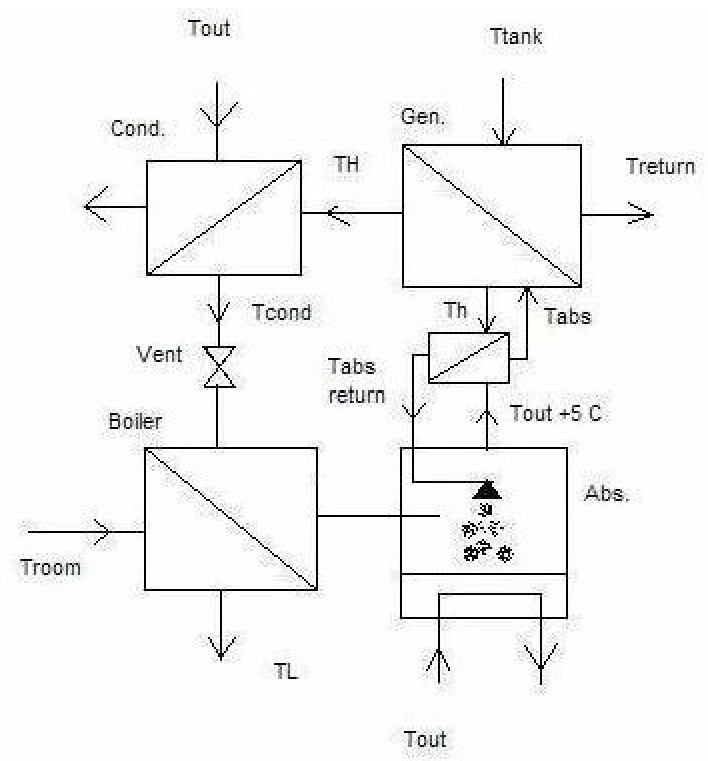


Figure 39. Absorption chiller system. The abbreviations can be studied in Appendix 10

4.5.5.1 Absorber

The absorber needs a working pair to operate. The working pair can be for example ammonia/water or water/lithium bromide where the former substance is the refrigerant and the latter is the absorbent. The absorber is where this working pair is mixed through absorption. The absorption process is an exothermal reaction which means that energy is released when the refrigerant and absorbent are mixed. To receive a high concentration of refrigerant and a good efficiency for the process, temperature needs to be kept low in the absorber.[96] This is done by cooling the absorber in a heat exchanger with the outdoor air or

[91] Holmér I., B.W Johansson, S Gyllerup, H Lundgren, 1996
[92] Zinko H., S-O. Söderberg, E. Fahlén, A. Gebremedhin, 2004
[93] Lorsch Harold G., Inc., 1998
[94] Rydstrand M., V. Martin, M. Westermark, 2004
[95] Eastop, McConkey A, 1993, *Applied Thermodynamics*, Fifth edition, ISBN 0-470-21982-3,
[96] Zinko H., S-O. Söderberg, E. Fahlén, A. Gebremedhin, 2004

cold water from a river or lake which is referred to as back cooling.[97] The absorption process gives raise to a pressure reduction necessary for the cooling process.[96]

4.5.5.2 Generator

The mix of high concentrated refrigerant with a low temperature is then pumped or flow by self circulation to the generator. The high temperature heat is added in the generator to separate the refrigerant from the absorbant.[96] It is important that the working pair has different boiling points to separate the refrigerant completely. This is a problem for the ammonia/water system. Small amounts of water will be vaporised even at temperatures under 100°C while the LiBr has the vapour pressure 0. This means that water will have to be separated again from the ammonia which reduces the efficiency. The heated absorbent will be re-circulated to the absorber, but is first heat exchanged against the colder stream from the absorber.[97]

4.5.5.3 Condenser

When the refrigerant enters the condenser it has a high temperature close to the generator temperature and a high pressure. The system is designed to reach a sufficiently high pressure to be able to condensate the refrigerant with the back cooling temperature. The goal is to receive a refrigerant with low energy content in the liquid phase with low temperature and pressure. Large amounts of energy can be drawn out from the cooling system through condensation. The low pressure is retrieved through a vent after the condenser.[98]

4.5.5.4 Boiler

The low energy refrigerant is heat exchanged against the medium that needs to be cooled, for example the air from a room. The refrigerant will easily take up the energy and will vaporize from the gained energy.[98] The gaseous refrigerant is returned to the absorber and the cycle can begin all over again.

4.5.5.5 Working Mediums

As discussed earlier the absorption chiller needs a working pair to operate. The most used ones are ammonia/water or water/LiBr but other mediums are possible.[99] Both systems have the advantage of being more environmentally friendly than the traditional compressor cooling mediums. Traditional compressor coolers use HCFC, a strong green house gas, as cooling medium. Ammonia and LiBr are not green house gases and do not add to global warming.[100] However ammonia will have to be handled carefully because it is a strong base and exposure to large doses can be fatal. Small concentrations of ammonia can easily be detected by the smell and irritation in nose and throat.[101] LiBr can also be dangerous, but only in large amounts and should not be consumed.[102]

The most frequently used cooling pair is water/LiBr because it is used in air conditioning devices. The ammonia/water system was used in refrigerators but was taken out by the competition from the compression coolers. The ammonia/water system can produce a cooling temperature below 0°C which is impossible for the water/LiBr system as the water in the system will freeze. The conventional ammonia/water systems have many drawbacks, like lower efficiency, complex construction and the risk of leaking. Despite these drawbacks this

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[97] Holmér I., B.W Johansson, S Gyllerup, H Lundgren, 1996
[98] Alvarez H., 2003
[99] Cogeneration Technologies, 2007
[100] Yunho Hwang, 2003
[101] CCOHS, 2007
[102] Gfs chemicals, 2007

system has the biggest potential for small scale use as it can use lower powering temperature and be cooled by the outdoor temperature.[103]

4.5.5.6 Hydrogen in the Process

The absorption chiller with the ammonia/water can be powered completely without electricity. Some manufacturers do this by adding hydrogen to the cycle. Hydrogen has the benefit that it will circulate in the low pressure part of the system as gas while the ammonia is absorbed and vaporized. The total pressure is held constant in the system which will lead to lower partial pressure for the ammonia as it is mixed with the hydrogen. It is only the partial pressure for ammonia that is important for the temperature at which it will condensate and vaporise.[104] There are also absorption chillers that use a steam cycle to make the process run without electricity.[105] The circulation between the absorber and the generator can be achieved by heating the flow of high concentrated cooling medium in the pipe. The heated medium will rise due to a lower density.[104]

4.5.5.7 Effect Calculations

The COP of the absorption chiller can be calculated by knowing the input temperatures in the system. This COP is called Carnot cooling factor as it is the theoretical maximum. These calculations can describe how much energy the input energy can remove from the cooled space without taking into account the heat losses within the absorption chiller. This equation can be written as follows:

Equation 2. Ideal Carnot cooling factor.

$$COP_n = \frac{T_{gen} - T_{cond}}{T_{gen}} \cdot \frac{T_{boi}}{T_{cond} - T_{boi}}$$

The temperatures in the equation are the temperatures out from the components and can be seen in Figure 39. This requires that all the thermodynamic processes in the system are ideal, reversible and at constant temperatures. This is not the case. The cooling factor needs to be adjusted because the concentration and solubility of refrigerants in the system is temperature dependent. This can be described by a reduction factor (R).

Equation 3. Reduction factor.

$$R = \frac{T_{cond} - T_{boi}}{T_{gen} - T_{cond}}$$

This means that the Carnot co-efficiency can be written as:

Equation 4. Carnot cooling factor[106]

$$COP_n = \frac{T_{boi}}{T_{gen}} \cdot \frac{1}{R}$$

[103] Holmér I., B.W Johansson, S Gyllerup, H Lundgren, 1996
[104] H Alvarez, 2003
[105] Jendretzki D., Interview 2006-11-03
[106] Zinko H., S-O. Söderberg, E. Fahlén, A. Gebremedhin, 2004

To evaluate the real cooling factor for a thermodynamic process it would need to be tested or compared with similar processes. Through tests, a co-efficiency of the Carnot cooling factor can be calculated for the process. The real cooling factor for an ammonium absorption chiller can vary between 0-2.[107] The cooling factor is defined as the relationship between the produced useful energy, in this case the energy taken from the cooled area, and the input energy that the process uses.

Equation 5. Cooling effect. [108]

$$COP = \frac{P_{useful}}{P_{input}}$$

$$P_{useful} = COP \cdot P_{input}$$

4.6 Model of Solar Panel/Absorption Chiller-System

This chapter will give an overview of the most important components in the sp/abc-system. The most important parts of the model which are presented here are; the solar panel, the absorption chiller and the base case model house. Also a small evaluation of the base case house is conducted. Information on where data on the different parts are taken from will also be presented. An overview over the model can be seen in Figure 40.

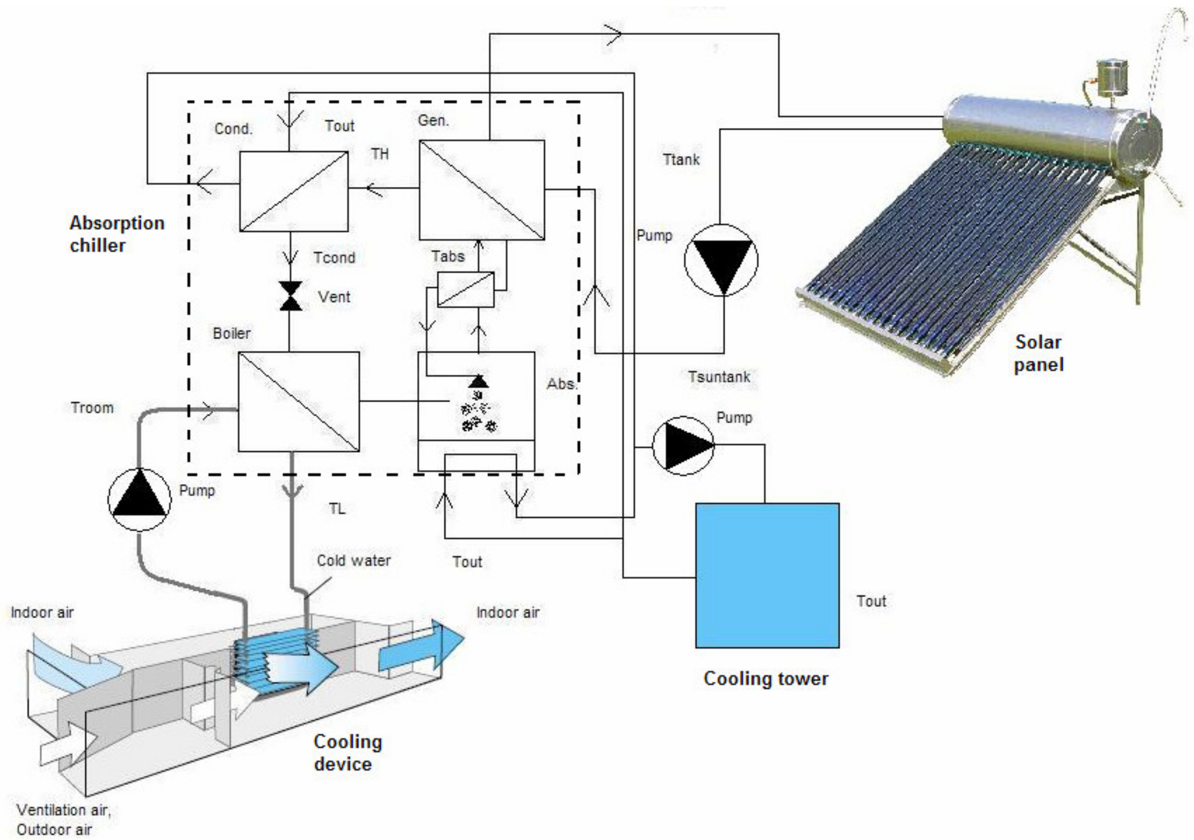

Figure 40. Schematic overview over the proposed model.

[107] Technology update from Econicsystems, November 2006
[108] Alvarez H., 2003

4.6.1 ECONICsystems Absorption Chiller

The absorption chiller which is used for the modelling of the sp/abc-system was developed by SolarFrost and will be commercially available through ECONICsystems as of 2008. ECONICsystems purchased the rights to manufacture, distribute and sell the cooling machine in 2006. The research and development started in 1996 and ten years later the aAa, advanced ammonia absorption was presented as a prototype. The big technological improvement that SolarFrost has achieved is that the absorption chiller can be powered by low temperatures between 80 – 120°C. The former absorption chiller processes needed a power source with at least 150°C. Now the absorption chiller can be powered with a solar panel and be cooled by outdoor air with a temperature up to 50°C.[109]

The solar powered absorption chiller is still not commercially available, but first ß-version machines will be available as of April 2007. The price will be high during the first years. The estimated price for a single order of 1000 units will be around $ 2500 each.[110] This can be compared to the traditional air-conditioning devices sold in Ecuador with a price from $ 300 with 2 kW in cooling effect.

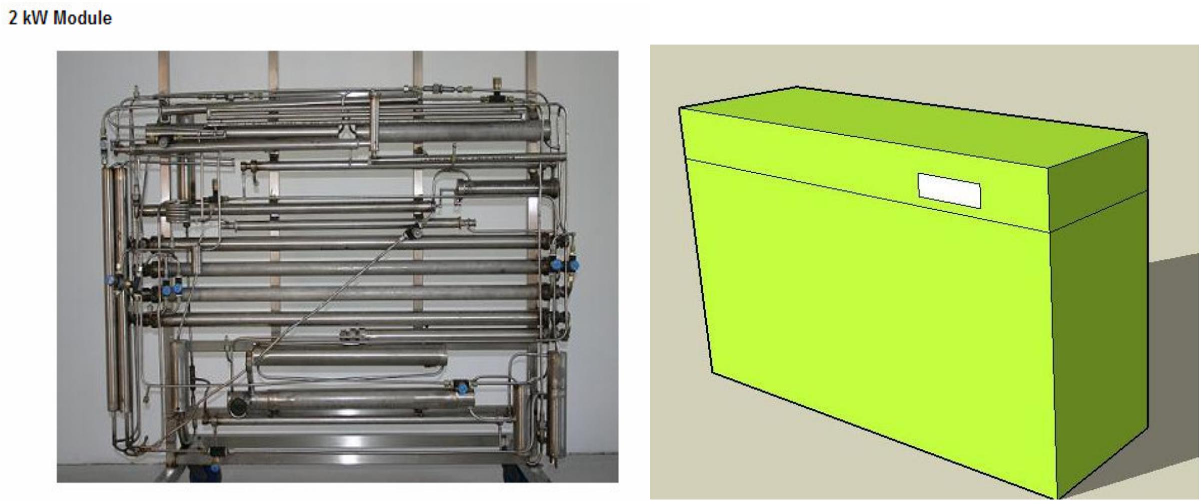

Figure 41. Two pictures of the SolarFrost absorption cooling machine.

SolarFrost has calculated the theoretical COP based on the three temperatures of operation powering, cooling and back cooling. The results can be seen in Figure 62.[111]

The powering temperature is decided by the solar panel system. The temperature out from the solar panel accumulation tank will be the powering temperature. In other large scale applications with an absorption chiller and a solar panel the solar panel system is designed to achieve a mean temperature in the system of 90°C.[112]

The absorption chiller system is supplied without a cooling distribution system. This system is an additional cost and the choice of the system will change the COP for the process. A short background to the different processes is made in the heat exchanger theory chapter 4.5.4. Some of them do not use electricity, which makes them suitable cooling alternatives for Guasmo. These are radiation coolers, induction systems and systems that use cooling baffles.

[109] SolarFrost, 2007
[110] Jendretzki D., Interview 2006-11-03
[111] Technology update from Econicsystems, November 2006
[112] Solel, 2006

The two last mentioned systems work similarly, while the radiation cooler works very differently and requires a different cooling temperature. The radiation coolers or cooling grids need a temperature of 15°C and the others 5-10°C, which makes the absorption chiller process more effective if the radiation coolers or cooling grids would be used. The problem for this system is however that it only reduces the temperature of the floor, walls and other things in the room and leaves the air temperature relatively unchanged. This means that no or small changes will be made in the air humidity. It is hard to determine which of the cooling devices that will be most favourable for the houses in Guasmo. The ECONICsystems absorptions chiller system is designed for a cooling grid and can only provide room cooling. According to the Givoni bio-climate diagram the climate of Guayaquil needs dehumidification to reach the comfort zone during large parts of the year and it might be better to install a cooling device like the induction cooler that can reduce the humidity in the air as well as lower the temperature.[113] Therefore the sp/abc-system is calculated with a cooling temperature of 10°C that will suit all the cooling solutions.

The ECONICsystems absorption chiller system requires three electrical pumps that can transport the hot water from the solar panel tank to the absorption chiller and back again. Pumps are required between the absorber and a cooling tower that is placed outside the house and from the absorption chiller to the cooling device in the house. The power required for the pumps is estimated by ECONICsystems to 150 W for each 2 kW chiller module. This amount may vary depending on the distance between the different parts of the system.

4.6.2 TechnoSol Solar Panel

The data for the solar panel is collected from two solar panel companies, TechnoSol and Solarit AB. TechnoSol is a company that sells solar panels in Ecuador and the other company is Swedish and also sells solar panels. Information from the Swedish company was used to complete the missing data for the model used to simulate the system. Both the Swedish and the Ecuadorian systems use the same technique. The data from the Ecuadorian solar panel can be seen in.

Table 6. Data for the vacuum solar panel TS190.

TechnoSol Solar panel data	
Model name	TS190
Collector area	3.9 m^2
Tube area	2.37 m^2
Tank volume	190 m^3
Tank insulation	141B
System volume	20 m^3
Tank length	1.89 m
Weight, empty system	50 Kg
Angle	30°
Price	$ 1000

Source [114] [115]

Table 7. Data over the similar Swedish solar panel.

Solarit AB	
K_e	63 %
Reflection in glass	2 %
Insulation thickness	55 mm

The data that was needed from the Swedish model was the information about the vacuum tubes and the insulation thickness. These can be seen in Table 7. The picture of the solar panel system which can be seen in Figure 42 is also from Solarit AB as no picture was allowed to

[113] Givoni B., 1998
[114] TechnoSol, 2006
[115] Solarit AB, 2006

be used over the TechnoSol system. The difference between the systems is that the Swedish system is smaller and the tank is wrapped in metal. The TechnoSol solar panel has a layer of plastic around the tank. The panel in the picture is only 1.9 m^2.

Figure 42. The vacuum solar panel system.

4.6.3 Building Model for the Simulations

From the gathered information about the houses in Guasmo, a standard house for the area was modelled in DEROB-LTH, which is a computer simulation program with which it is possible to simulate the indoor climate and thermal comfort in buildings. A model of a house was constructed using the physical properties for the materials of the roof, floor, walls and windows. A climate file with the hourly data of outdoor temperature as well as direct beam and diffuse solar radiation are used as input data. Indoor temperature and required cooling loads to keep a desired indoor temperature can be retrieved from the program which makes it easy to evaluate results of proposed improvements.

The Guasmo standard house was modelled as a one story building with two windows, one on the south and one on the north side. The house was constructed of concrete hollow blocks and galvanized steel roof and had a living area of 90 m^2. The houses did not have ceilings and ventilation was generally perceived to be poor, all of which was extracted from the questionnaire in Appendix 4. The standard house is similar to the building shown in Figure 43.

Figure 43. View over a typical house in Guasmo.

Most of the houses are built in rows with the effect that two sides of the house are shaded. The roofs are normally constructed with a small inclination as can be seen in Figure 43. The roof is however made flat in the simulation to simplify the model. The base case house and its geometry are shown in Figure 44. The windows were placed opposite each other and were set to be 1.5 m wide and 1 m high. They were both assumed to be single-glazed and their physical properties can be found in Appendix 13.

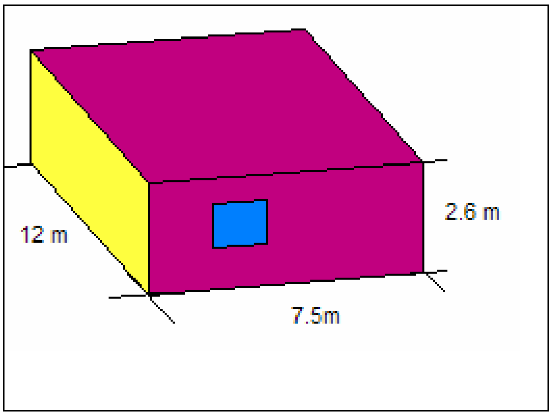

Figure 44. Simulated house in DEROB-LTH.

Traditional building materials were used in the model and their conductivity, specific heat and density were taken from the literature.[116] An overview over the different materials used in the building elements can be studied in Table 15 in Appendix 13. The hollow blocks are produced locally and they are made of concrete with two or three holes in the middle. The blocks used in the standard house are assumed to have a dimension of 100x400x200 mm. The blocks can be seen in Figure 45. The floor in low-income houses normally has a thickness of 50 mm,[117] but to compensate for the thermal mass of the inner walls and furniture in the room, the floor has been set to 100 mm.

Other important parameters are how the people spend their time in the house, how the house is ventilated and how it is furnished. All of these things affect the indoor temperature. Every living person produces heat, which is called internal load and is assumed to be 100 W per person. The internal load was calculated based on the questionnaire in Appendix 4. The schedule for one day can be seen in Table 8.

.

Table 8. Number of persons in the room during a 24 hour period.

Hours of the day	Persons in the house
8 am-11 am	3
11 am-2 pm	4
2 pm-7 pm	5
7 pm-8 am	6

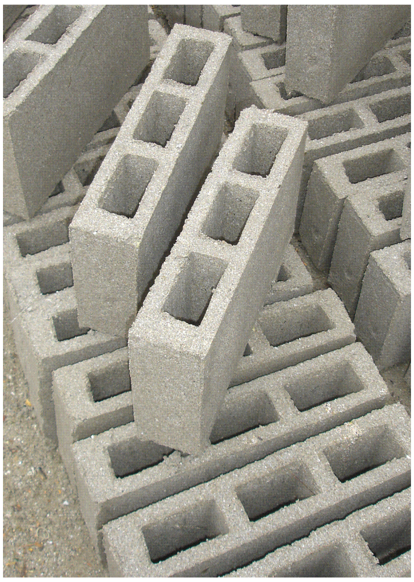

Figure 45. Hollow blocks used in Guasmo.

The most difficult approximation to make is the infiltration, that is, how many air changes the house has every hour. The house was assumed to have an infiltration of 2 air changes per hour.

The simulated temperature for the base case in DEROB-LTH was finally compared to temperature measurements made by other students from LTH in a similar house. The result can be seen in Figure 47. In this figure the indoor temperature was simulated using the average climate for January as input. The other students' investigation was conducted during

[116] Johansson E., 2003
[117] Johansson E., Interview, 2007

three days in January 2006 and their measured outdoor temperature was therefore compared to three standard January days for Guayaquil to see how well the measured outdoor temperature correlated with the outdoor temperatures for the three January standard days from Meteonorm. This can be seen in Figure 46.

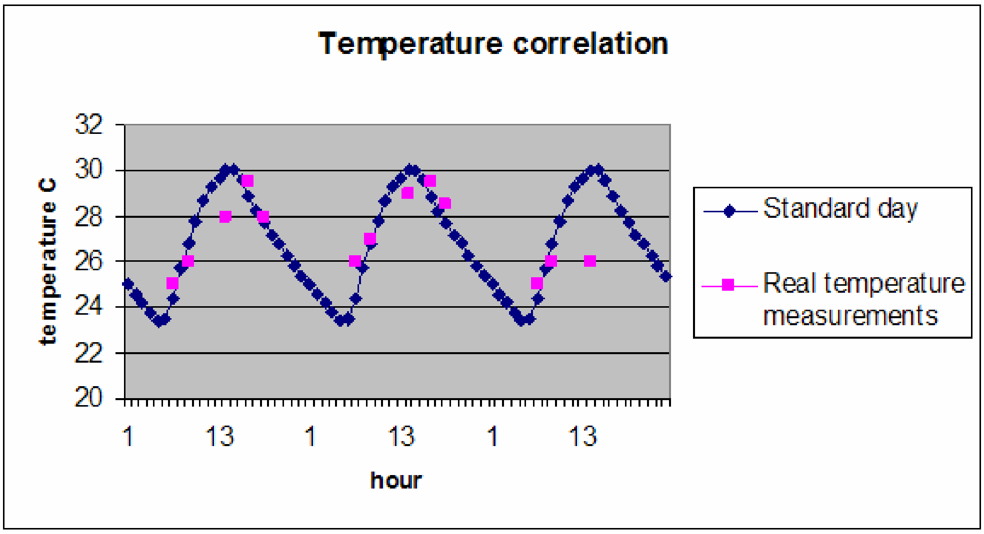

Figure 46. Comparison between the measured outdoor temperature during three days and the average outdoor temperature in January.

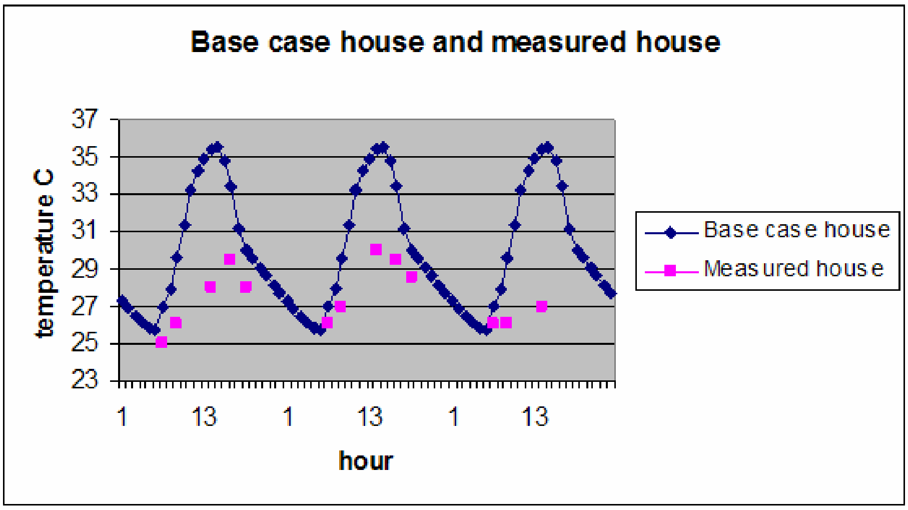

Figure 47. Comparison between the measured and simulated indoor temperature during three days in January.

The materials in walls and roof were similar for the house in which the measurements took place and the base case house. The big differences are the sizes and the numbers of rooms in the houses. The base case house has an area of 90 m^2 and one room while the house in which the measurements took place only has an area of 60 m^2 but two rooms. A parameter that can be different is the wind speed that can lower the temperature by a higher infiltration than the one programmed in the base case. The fact that the measured house might have a higher infiltration simply due to its different construction is also important as well as the fact that the simulated indoor temperature in the base case in Figure 47 is for three mean January days which are generally warm, whereas the measured indoor temperatures in the compared house are no mean values and can therefore be lower. Finally the yearly temperature fluctuation for the base case house was simulated which can be seen in Figure 49.

Figure 48. Picture of the house which the temperature in the base case was compared to.[118]

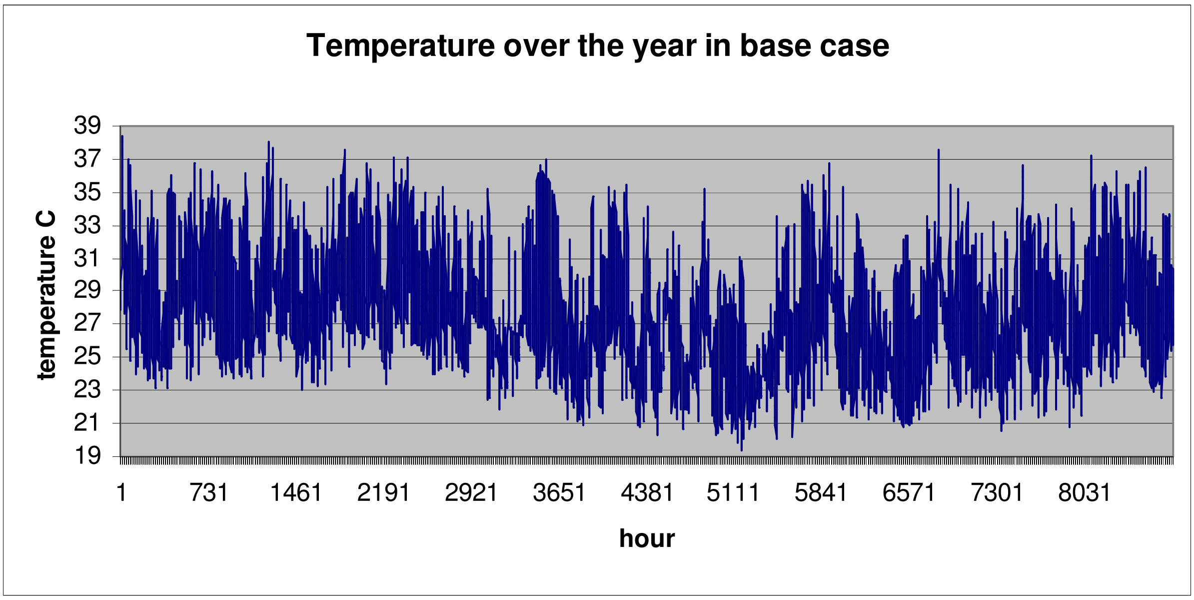

Figure 49. Simulated indoor temperature of the base case house.

4.7 Results of Solar Powered Air Conditioning Investigation

4.7.1 Cooling Effect from the Sp/Abc-System

The sp/abc-system is controlled by electric pumps to transport the water from the tank in the solar panel system and the cooling water to the absorption chiller. One of these pumps controls the transferred effect from the solar system to the absorption chiller by regulating the

[118] Chevez V., F. Lucca, 2006

flow of water from the tank. In this study, two different regulations have been investigated. One way was to let the pump work constantly with a set and constant flow and only be turned off when the temperature in the house reached the desired temperature or when the temperature was too low in the tank to produce cooling. The other method was to have daytime regulation which meant that the chiller was run from 11 am -7 pm and an effect of 2000 or 1400 W, depending on the season was taken out. The temperature in the house and the solar radiation is higher from October until the end of March. The energy can not be saved in the small accumulation tank and to optimize the energy from the sun a higher mean effect could be used during this time of year and a lower from April to the end of September. The solar radiation and the need for cooling are also higher during the day and the sp/abc-system could therefore be run only during the daytime with a higher effect.

The constant cooling effect is based on the mean solar radiation that can be captured by the solar panel. The solar panel system has heat losses that will reduce the energy production in the solar system. The calculation for the mean cooling effect out from the absorption chiller can be studied further in Appendix 10. The sp/abc-system can cool the house with an effect of 600 W every hour of the year under the condition that the temperature in the tank is higher than 80°C. The effect out from the tank will vary with the temperature as well if the flow of the pump is held constant. This effect is however based on the mean temperature in the tank.

The regulated cooling effect is based on the mean effect possible to take out from the tank. The solar radiation is 30 % lower during the cold period, April to the end of September and the cooling effect is therefore adapted to have 30 % lower cooling effect during this time. The cooling time is set to 8 hours between 11 and 19. This means that 2000 W cooling effect can be taken out from the absorption chiller from October to the end of March and 1400 W can be taken out from April to the end of September. The calculation for the regulated cooling effect can be studied further in Appendix 14.

Figure 50 to Figure 53 show how the temperature in the tank varies depending on the cooling effect and the solar radiation. The climate data is from the Meteonorm reference year for Guayaquil. It can be seen that the temperature in the tank is less stable for the mean cooling effect due to the cooling process at night when there is no addition of energy from the sun. The regulated cooling can also use more of the solar radiation. The temperature reaches 100°C more frequently for the mean cooling and then no more energy can be stored in the tank. It can however be noted that the regulated cooling is more sensitive for days without sun shine. This can be seen if the temperature in the tank is compared to the solar radiation during the end of the week. The temperature will sink more quickly below 80°C for the regulated cooling.

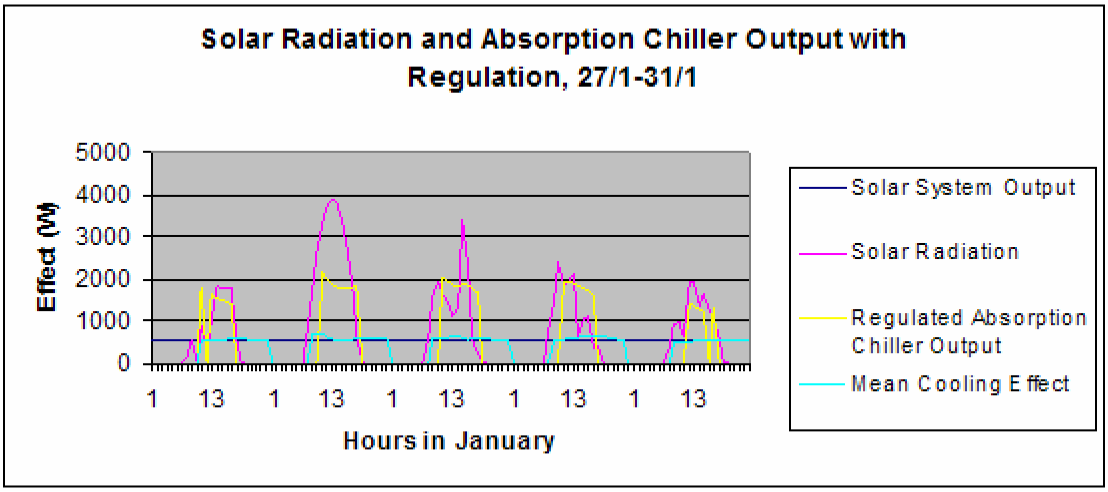

Figure 50. Mean and regulated cooling effect together with the solar radiation that hits the solar panel.

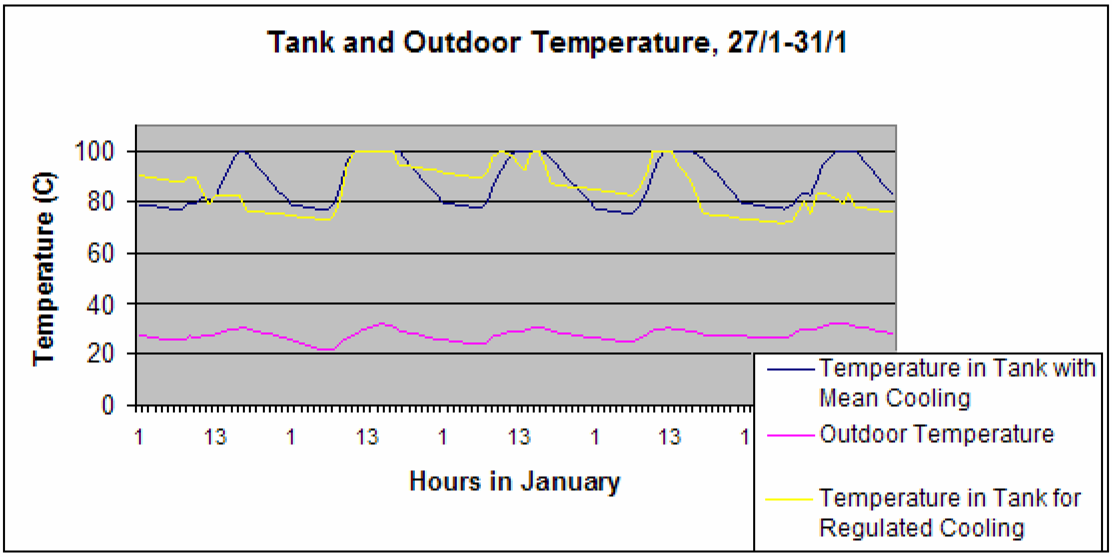

Figure 51. Tank and outdoor temperature for the mean and regulated effect for the five last days of January using climate data from Meteonorm.

The calculations for the whole year shows how many hours the temperature in the tank is lower than 80°C and these are the hours that the absorption chiller will not work. If one takes out the mean cooling effect during one year 50 % of the hours have lower temperature in the tank than 80°C. For the regulated cooling effect this number is 22 %. If the year is divided in halves the cooling machine is not functioning 24 % of the time between 1 April- 31 September and 20 % for the period October 1st – March 31st. The temperature in the tank for the regulated cooling can be studied in Figure 53 and how the two regulations differ is visualized in Figure 52 for the month of February. This calculation is described in Appendix 10.

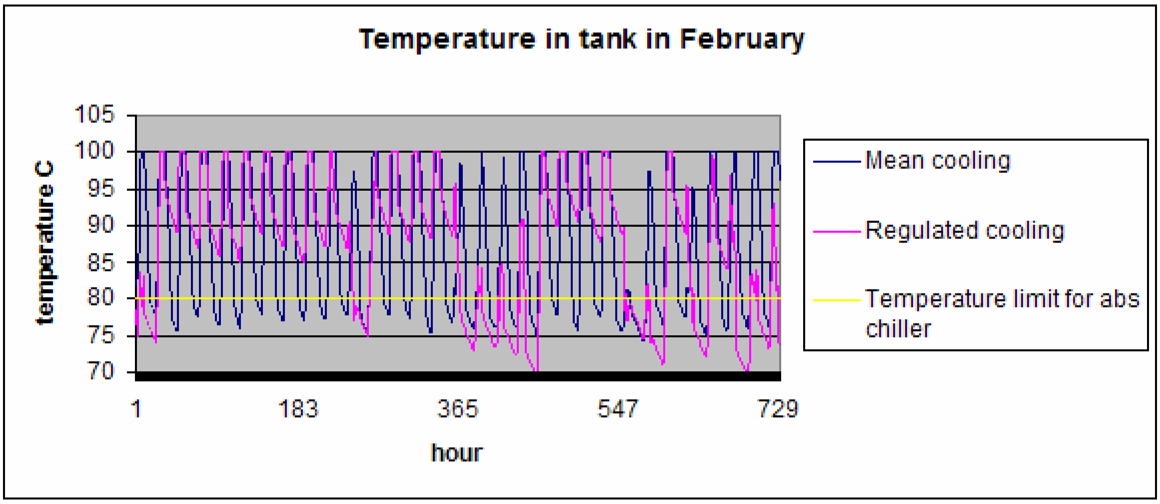

Figure 52. Temperature variation in the tank for regulated and mean cooling in February using climate data from Meteonorm.

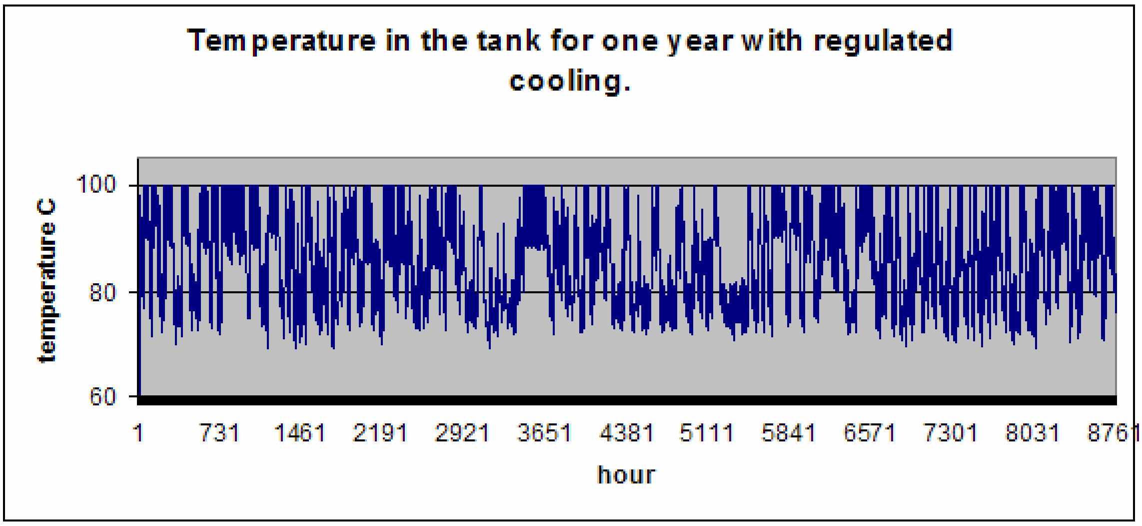

Figure 53. Yearly temperature variation in the tank for the regulated cooling using climate data from Meteonorm.

4.7.2 Influence of the Cooling Effect on the Base Case

When running the simulation of the base case house with regulated cooling the temperatures displayed in Figure 54 were obtained. As can be seen the temperature fluctuates between extreme values of 20-34°C, but most of the time the temperature lies between 23 and 29°C see Figure 54. Considering that the annual mean temperature in Guayaquil is 25.7°C the temperature inside the base case Guasmo house is pretty close. The interval between the numbers on the axis is 730 hours and thus represents approximately one month.

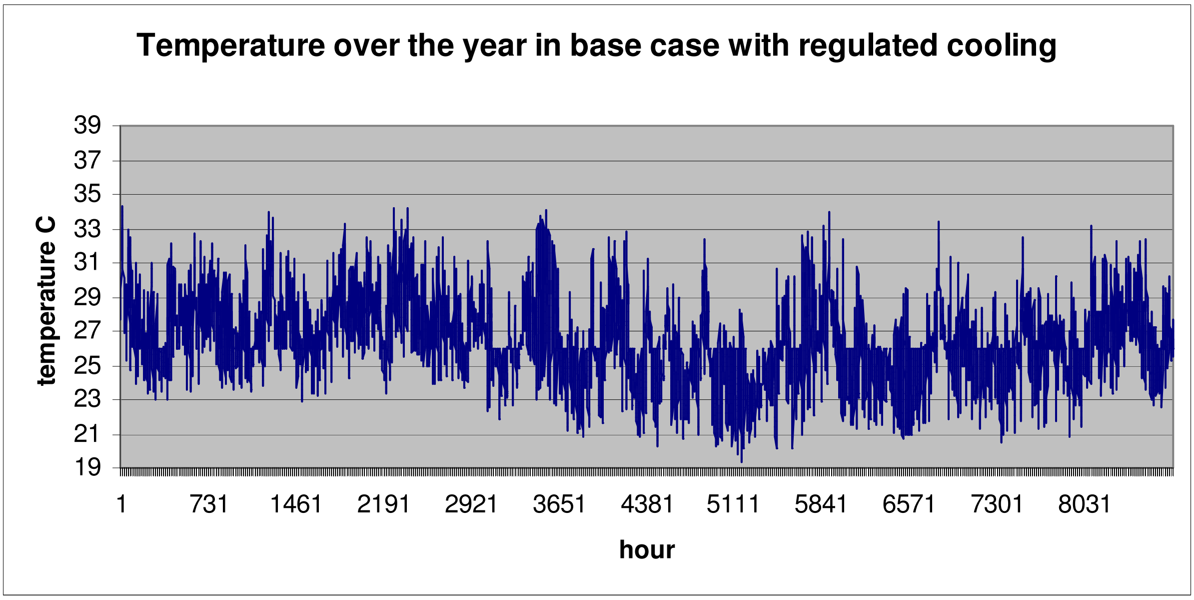

Figure 54. Temperature variation in base case house with regulated cooling.

However to be able to study the effect of the regulated cooling in more detail a shorter period of time must be studied. Therefore the last week of January has been chosen to make a more detailed comparison. The time interval of one week has been chosen because this is a short enough time period to be able to see effects in detail but it is also a long enough time to see how the cooling effect works from day to day. The months of January and February are considered to be the hottest of the whole year in Guayaquil and it is therefore interesting to see how the absorption chiller works in this period.

The regulated cooling from the absorption chiller is programmed with two different cooling effects, 2000 W for the period October 1st to March 31st and 1400 W for the period April 1st to September 31st. The absorption chiller is programmed to cool 8 hours every day from 11-19. It is programmed to do so because this period is considered to be the hottest period of the day and because it is more effective to cool with a higher effect for a shorter time than to cool with a low effect for a longer time, in the sense that the cooling machine has a higher reliability. Another detail in the regulated cooling is that the cooling device is set to cool to 26 °C. This means that the time during which the inside temperature is beneath 26 °C there will be no cooling even though it is between 11 and 19. The temperature 26 °C was chosen because it is thought to be comfortable for a majority of the people in Guasmo. The effect of the regulated cooling can be studied in Figure 55.

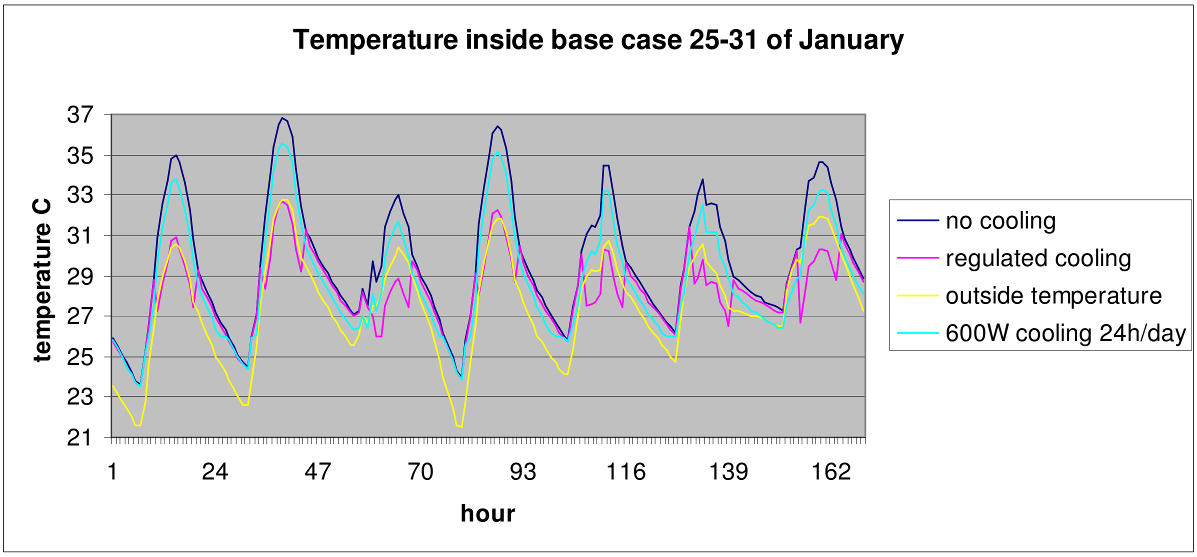

Figure 55. Comparison between base case house with and with no regulated cooling.

From the figure it can be seen that the regulated cooling cuts off about 4°C from the heat tops of midday. It can also be noted how the temperature in the case with regulated cooling follows the temperature in the case with no cooling during the morning and night hours and how the cooling directly has an effect on the temperature when it is turned on at 11 and how the temperature quickly elevates to the no cooling temperature and then follows it when the cooling effect is turned of.

4.7.3 Influence of Cooling Effect on Base Case House with a Ceiling

To try out the sp/abc-system further it has also been applied on a slightly modified base case house. The modification is that a ceiling has been inserted in the simulation model. The ceiling is placed 30 cm below the roof and by this the model is divided in two volumes. The ceiling is made of 25 mm gypsum and the number of air changes in this new volume is set to 3 compared to 2 in the larger volume. This is done because a ceiling is more effective if the air space above it is sufficiently ventilated. It is also common practice to insert perforated blocks in the upper parts of walls in Ecuador to elevate the air circulation and therefore this assumption does not seem unrealistic. The result of the ceiling can be studied in Figure 56. Here can also be noted a generally lower temperature than in the base case house. This is logical because a house with a ceiling in a tropical climate keeps a lot of heat radiated from the roof out and the house therefore warms up more slowly inside. However, this also applies to the cooling-off of the house and it occurs somewhat slower than in the base case house. Together it adds up to that in a house with ceiling the daytime temperatures are lower but the night time temperatures are somewhat higher.

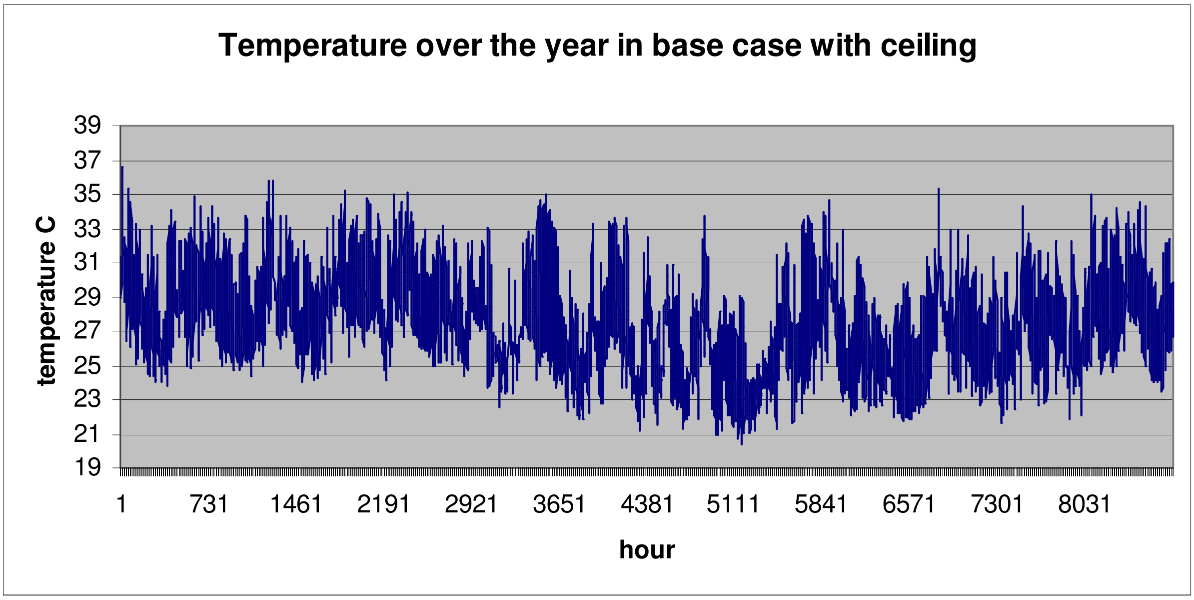

Figure 56. Temperature variation in base case house with ceiling.

If one compares the Figure 56 with the annual temperature graph for the base case house with ceiling and regulated cooling, Figure 57, it can be observed that the temperature in the case with regulated cooling almost has no temperature tops above 32°C whereas in Figure 56 they are numerous. One can also observe that generally there is less “noise” in Figure 57 and this means that the temperature curve has been smoothed out by the regulated cooling. The case with ceiling and regulated cooling can also be compared to the base case with regulated cooling and it can then be observed that in the base case with regulated cooling there are a number of temperature tops above 33°C. One can therefore draw the conclusion that the regulated cooling over the year has a slightly better effect on the house with ceiling than on the base case one.

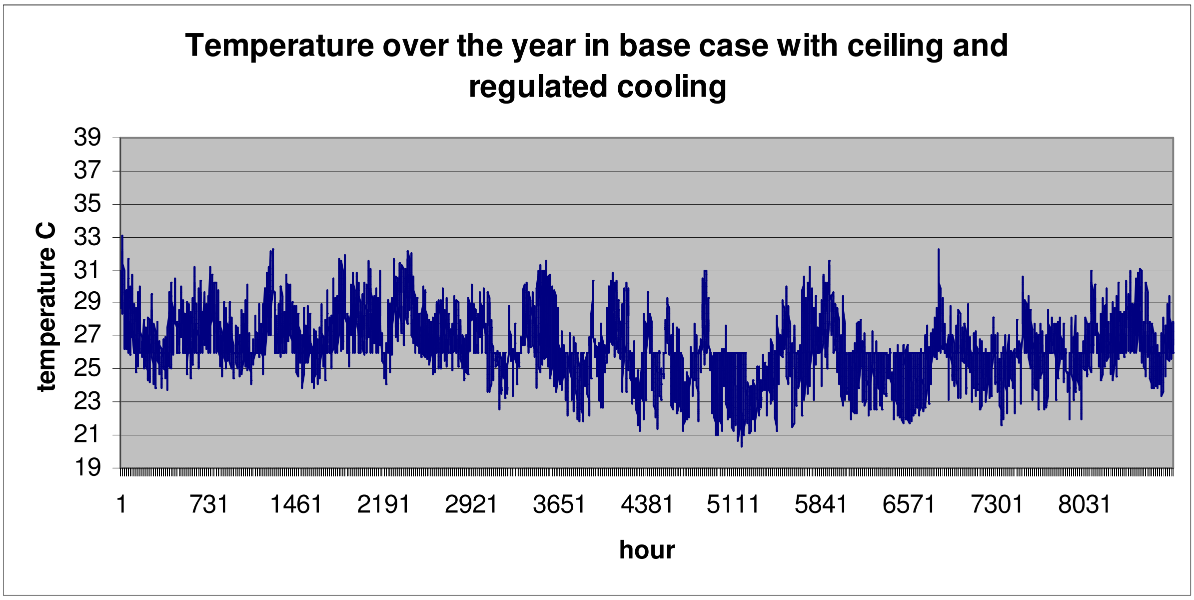

Figure 57. Temperature variation over the year in a base case house with ceiling and regulated cooling.

To study the effect of regulated cooling from the absorption chiller further a graph of the last week in January, 25th- 31st, was made and the temperature in the no cooling and regulated cooling cases were plotted parallel to each other just as in Figure 55. The result can be seen in Figure 58. The regulated cooling has been programmed in the same way as in the base case. When looking at this graph it can be noted that the regulated cooling also in this case cuts off about 4°C of the midday temperature tops. But in this case the highest tops are around 35°C and not 37°C as in the base case graph of the same time period. However it is not easy to say in which of these cases the regulated cooling has the largest or best effect.

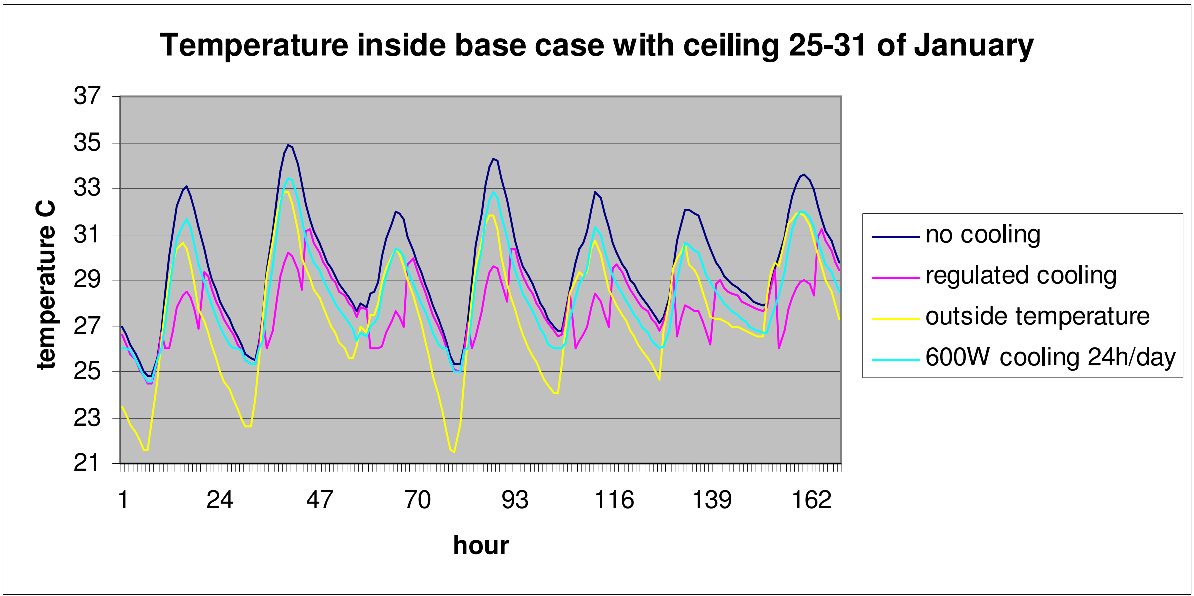

Figure 58: Comparison of the temperature variation the 25th -31st of January between the no cooling and regulated cooling case.

Finally a comparison between the effects needed to cool the base case house with ceiling to 26°C to the effect needed to cool the base case house without ceiling to the same temperature was made. It was found that instead of needing around 5000 W one in this case needs around 4000 W for the same period of time. It is therefore more effective to cool the base case house with ceiling than without from an energy efficiency point of view, which logically also should be the result.

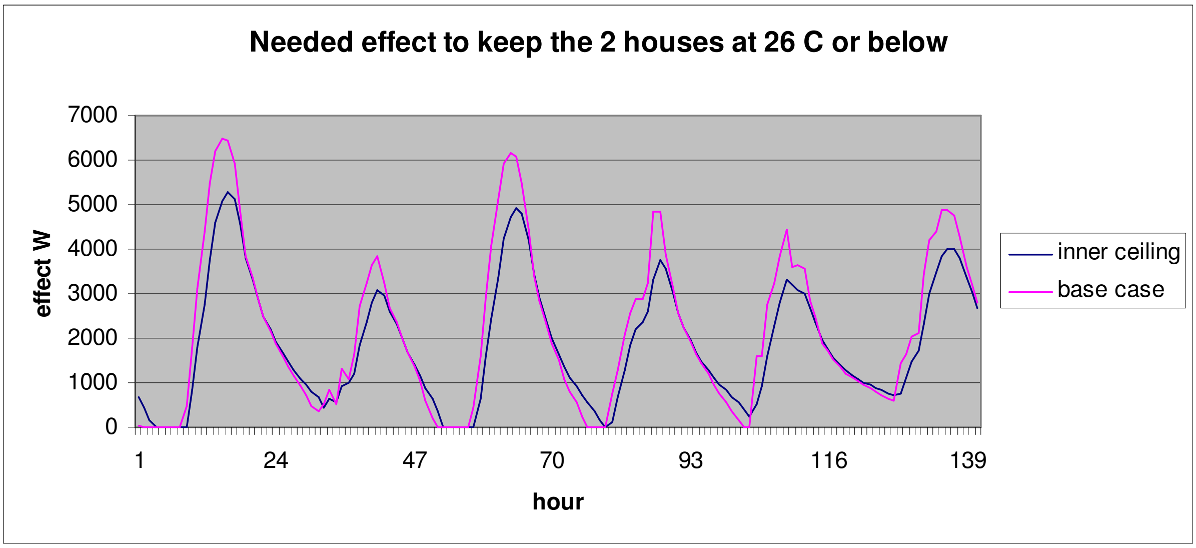

Figure 59. Effect needed to keep temperature in the two houses at 26°C or lower during 25-31st of January.

4.7.4 Optimization of Absorption Chiller Effect

A cooling device works better the smaller volumes of air it needs to cool. This can be achieved with reduced infiltration. It is however important to only reduce the infiltration when the absorption chiller is working as the infiltration will help reduce the indoor temperature during the night time when the outdoor temperature is low. The inlet of air from the outside can be controlled with e.g. hatches. The hatches should be closed during the day and opened again when the absorption chiller is turned off. The impact of reduced infiltration can be seen in Figure 60 in which the infiltration has been reduced from two to one air changes per hour between 11 am and 7 pm.

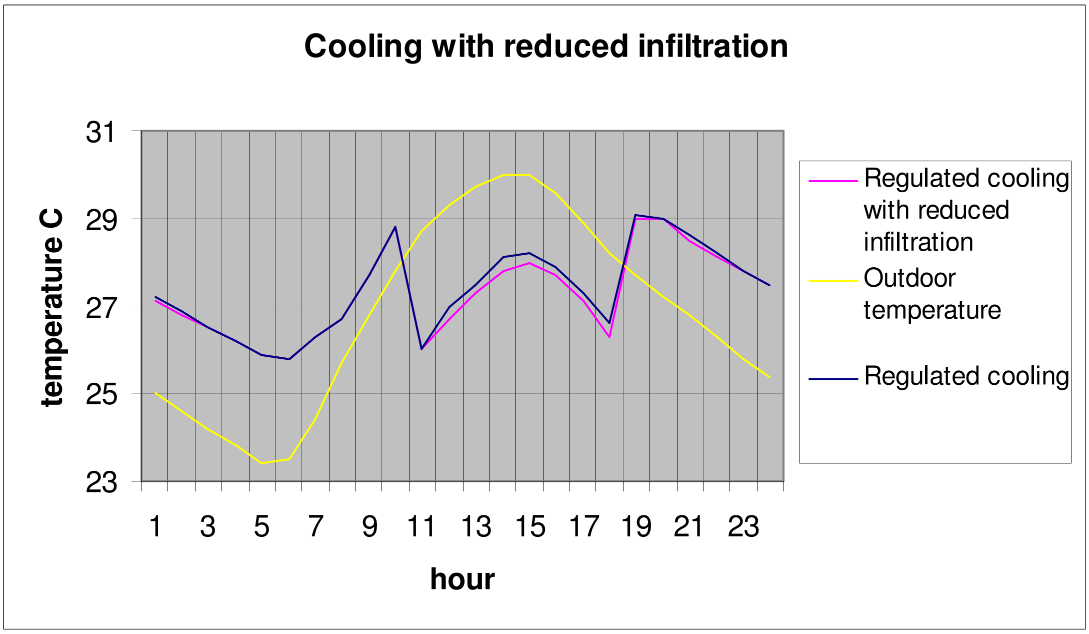

Figure 60. Cooling with reduced infiltration for a house with ceiling during a standard day in January.

4.7.5 Economical Prerequisites

As always the most important issue when evaluating investments is the economical and financial feasibility. This system as mentioned earlier utilizes new technologies (solar panel system and the absorption chiller). It requires a very high initial investment with very low operating costs. Unfortunately, this will pose a financial problem for most of potential low-income buyers.

The sp/abc-system is compared to a traditional air conditioning device as it is the competing technique. The annuity method without taking the inflation into account is used to calculate how much the different devices will cost during the working life time.[119] The price for a traditional air-conditioner was mentioned earlier to be $ 300 for a device with the effect of 2 kW. The COP for these air-conditioners varies between 1.7 and 3.3.[120] The modern models have a COP of 3 which is therefore chosen and used in the calculation. If the air-conditioner is used during the same hours as the sp/abc-system a total cost can be calculated. The systems are assumed to work 10 years and the price for electricity can be studied in Appendix 6.

The total investment cost for the sp/abc-system in the calculation comprises of solar panel, absorption chiller and the electricity consumption from the three pumps. The solar panel has a

[119] Persson I., S-Å. Nilsson, 2001
[120] Energy Smart Homes, 2006

price of $ 1000[121] and the absorption chiller has price of $ 2500.[122] The energy use was calculated with the same method as for the traditional air-conditioner with the same electricity price and running hours. The price for the absorption chiller is for 1000 units from ECONICsystems in Austria and can therefore be higher for the single customer in Ecuador.

The total cost is calculated to be $ 1900 for the traditional air-conditioner and $ 4000 for the absorption chiller. The calculation does not include the cooling device, pipes and the three pumps. No installation costs have been included for either of the system. These are all additional cost that will increase the price for the absorption chiller. They have not been included due to lacking information about costs for these parts.

4.8 Discussion of Solar Powered Air Conditioning Investigation

4.8.1 Applicability of sp/abc-systems in Guasmo

When the investigation now is completed one wonders if the sp/abc-system is the solution for the poor indoor climate in the low-income houses in Guasmo. The sp/abc-system is according to the authors well suited for the climate in Guayaquil. Large amounts of solar energy and a need of cooling all year round which means many working hours make out great prerequisites for the sp/abc-system. The large amount of sun and poor climate design makes the temperature in the houses very high during the daytime which makes the need of cooling higher when there is large amount of accessible energy from the sun. The houses in Guasmo have a bad climate design and they need a high effect from a cooler to reach a constant temperature of 26°C. This is the reason for the relatively small change in temperature in the houses from the mechanical cooling. 2 kW only reduces the temperature with 4°C. The authors believe that the sp/abc-system could substitute a traditional air-conditioner with 2 kW when looking to the technical performance, but the problem is the economy. This is why the answer to the question whether the sp/abc-system is suitable or not is no.

The investigation encountered something which is a classic dilemma in environmental science. The economy is making it impossible to implement new solutions with the aim to improve both the social situation and the environment at the same time. However, the investigation shows that there are several other measures that could be undertaken which can provide a better indoor climate for far less money and effort. Some classic examples that have been encountered in this investigation are e.g. installing a ceiling, maximizing the natural ventilation, painting the roof white etc. From the simulations of a base case Guasmo house in the last week of January without cooling, temperature differences of about 2°C between the house with and without ceiling can be seen. The effect of natural ventilation can be studied in the passage on optimization of the sp/abc-system and it can there be noted that the indoor temperature drops somewhat when the number of air changes in the model is lowered from two to one. One would expect a large drop in the indoor temperature because that there would be a smaller volume of air with outdoor temperature entering that the cooling system would have to cool, but only a small drop can be noted. This signifies that the cooling effect from the outdoor air on the indoor temperature is great.

4.8.2 Model of Solar Panel/Absorption Chiller-System

The functionality of the model is determined by three values; produced cooling effect, reduced temperature in the house and reliability of the system. The produced effect is depending on how much energy that can be retrieved from the solar panel system. The

[121] TechnoSol, 2006
[122] Jendretzki D., Interview 2006-11-03

TechnoSol solar panel used in the model has a 4 m^2 vacuum solar panel that retrieves a mean effect of 580 W without including the heat losses. The captured energy from the sun minus the heat losses is what the sp/abc-system can use for cooling. Two cooling effects were investigated and it can be seen in the result chapter that the system is better used with the regulated 2000/1400W cooling. There are many reasons for why this regulated cooling is better. First of all no cooling take place during the night which makes the temperature in the tank more stable, more energy is taken out from the tank during the day when there is a risk that the temperature in the tank reaches 100°C and no more energy can be stored. The natural cooling effect can be used better from the lower outdoor temperature during the nights. This can be seen by studying the temperature figures of the tank and the base case house. The regulated cooling has also a higher reliability compared to the mean cooling. The system will malfunction 50 % of the working hours with the mean cooling and only 22 % with the regulated cooling. With the regulated cooling 2 kW cooling effect can be produced from the sp/abc-system which is the maximum effect. If the system was to produce 2 kW between April 1st and September 31st as well a larger solar panel would be needed and would then be over dimensioned between October 1st and March 31st.

The indoor comfort in the base case house is very poor. This can be seen by studying the indoor temperature in Figure 54. The indoor temperature reaches 37°C during the studied week of January. This is a very high indoor temperature and it requires a large cooling effect to reduce the temperature. According to simulations which can be seen in Figure 59 it would require a 6 kW absorption chiller to have a constant temperature of 26°C inside the house. This indicates that something needs to be done to improve the indoor climate. However it is not economically possible to reach a comfortable indoor climate by implementing mechanical cooling. Other changes will have to be made first, like constructing a ceiling. The effect of 2 kW is only enough to lower the temperature in the base case house with 4°C. This is not a large temperature reduction for the effort it takes to install a sp/abc-system. It is easier and more economical to construct a ceiling that will reduce the temperature with 2°C. The positive thing is that a ceiling and a sp/abc-system can be combined and a maximum temperature reduction of 6°C can be achieved. It has to be remembered that the house has a large living area that the sp/abc-system is trying to cool down. It will probably be better to apply the cooling in only one room of the house. If it is possible to reach a low temperature in the house or in one room the effect can be increased with reduced infiltration. This can be seen in the chapter about *Optimization of Absorption Chiller Effect* where the temperature is lowered when the infiltration is reduced. The temperature in this case is only somewhat lower but the effect will be bigger when the temperature difference between indoor and outdoor is higher.

When looking at the reliability for the sp/abc-system it can be concluded that the regulated cooling is better than the mean out take as has been discussed earlier. But even the reliability for the regulated cooling can seem to be low. The system will malfunction one out of five hours. This is because the system is very dependent on a daily addition of heat from the sun. Only a couple of days with no or little sun shine will make the temperature drop under 80°C and the system will stop working. This can be prevented by an electric boiler as can be seen in Figure 39. Then the temperature in the tank is held on a minimum level so that the sp/abc-system always can be functional. This will however increase both the cost for the system and the use of electricity. It will probably be more economical and easy to have the system as it is. The advantage with the sp/abc-system is that it will only malfunction when there is no sun and therefore less need for mechanical cooling.

The proposed model of the sp/abc-system is found to be appropriate for the regulated cooling effect. The retrieved effect is the maximal possible for the working hours for at least half of the year and it can substitute a traditional air-conditioner with the same effect. It is however hard to tell whether the system has a reasonable reliability or not. That is connected to how the system is used and when the system is out of order. The malfunctioning affects the indoor climate differently if it occurs for a whole day or just the two last hours of the daily cooling and it is only the opinion of inhabitants that can decide if there is an uncomfortable indoor climate when the system is out of order. The model needs to be investigated further theoretically and then be tested in a pilot test before the combination of the system can evaluated thoroughly.

4.8.3 Economical Benefits

It has been said earlier that the absorption chiller system is too expensive for the inhabitants in Guasmo. The price for the sp/abc-system is at least twice the price of a traditional cooling device over a ten year period with the present electricity price in Ecuador. It is therefore more profitable to invest in a traditional air-conditioner instead. It is however hard to predict the future electricity price which will have a great impact on the running costs for the traditional air-conditioner. The price on the absorption chiller will probably be lower in the future when it is produced in large quantities, but the question is whether the financial situation for the people in Guasmo ever will make it possible to buy a sp/abc-system. A big problem for the inhabitants is that they rarely have the possibility to make large investments that will be profitable in the long run. This is mainly the reason for the houses with poor indoor climate that today need to be cooled with cooling machines to be comfortable. A possibility to make the sp/abc-system available for the low-income people could be if the government gave financial support for this type of technology.

4.8.4 Environmental Benefits

If the sp/abc-system was to be applied it would have several environmental benefits such as a lowered consumption of electricity. As have been said earlier, in the case of the Guayas region the electricity is produced from natural gas which is a fossil source of energy and to lower the consumption of it would directly effect the emissions of carbon dioxide in the area. Another environmental gain with the sp/abc-system is that the cooling medium in the machine is free from freon. This means that when the machine is discarded there will be no damage to the ozone layer. Considering that there still is a high usage of freon in South America this would be an important improvement. The environmental drawback of using the proposed sp/abc-system is ironically that the foam insulation material on the “TechnoSol” solar panel contains HCFC 141b, which is a type of freon. Production of this HCFC was prohibited in the United States after the 31st of December 2002. But another insulation material for the tank or another comparable solar panel should not be hard to find.

4.8.5 DEROB-LTH

Still another important thing to discuss is whether or not DEROB-LTH is the proper tool for testing the effect of the sp/abc-system as the computer program does not take into account air humidity. The humidity is of great importance in means of sensation of comfort and would have been interesting to incorporate in the model somehow. However, this is not possible in DEROB-LTH and another simulation tool maybe would have been better. The cooling effect from the wind is also important for determining the indoor climate and comfort in a house. In this model the outside wind is accounted for by adjusting the hourly number of air changes inside the house. The problem is to know the correct value and measurements of this parameter would have been useful.

4.8.6 Base Case House

A base case house was modelled with data from the questionnaire and as it is based on mean values for the different building elements this is only a fictive house. It is important to note that the information about the houses is received from only one out of 30 sectors in Guasmo and the standard is quite varying between the sectors in the area. Some areas have only bamboo or block houses while others have a mix. Since the information in the questionnaire was gathered on foot, the multi-storey houses might be under represented in the study which could affect the standard house. Other information that could have been useful is how many rooms the houses had.

The base case house is thought to react like a real house in the simulations, however this is something that has not been tested thoroughly. The base case house has been compared to a similar house but from another residential area and with a smaller floor area. This is something that affects the reliability of the simulations. The comparison showed that the simulated outdoor temperature has a good correlation with the measured one but that the base case house has a 5 °C higher indoor temperature than the compared house during the hottest hours of the day, see Figure 46 and Figure 47. This signals that the simulated indoor temperatures in the base case can be too high which might depend on that the infiltration in the simulation is too low. But it is very hard to say because it might also depend on that the measurements were taken on a colder or cloudier day than the normal January days used in the simulations of these indoor temperatures.

4.8.7 Validity of Results

The calculation of the possible retrieved effect out from the solar panel system is based on many assumptions and some are more important than others. Our climate data, containing solar radiation and temperature is received from the climate simulation program Meteonorm which was mentioned in the background to this chapter. This is an acknowledged program, but can be less precise for developing countries like Ecuador due to lacking solar radiation, temperature and humidity data. The lack of accurate data will have consequences all the way through the calculations as they are based on the solar radiation and outdoor temperature. Climatic measurements in the area of Guasmo would have been desirable, especially wind speed and humidity that has large influence on the heat losses from the tank, solar panel and the house. The convection coefficient used to calculate the heat loss from the tank is highly dependent on the wind speed and humidity. Another assumption made is that the heat losses from the pipes are so small that they can be neglected. This is highly dependent on the length of the pipes and how well they are insulated, something that might effect the result. The most important values used in the calculation with their standard deviation can be studied in Table 9.

Other approximated values that might tamper the result are the values taken from the Swedish solar panel and used as if the Swedish solar panel was identical to the Ecuadorian solar panel which is not the case. The Swedish model might have a better efficiency compared to the TechnoSol panel.

As for the solar system the calculations for the absorption chiller might be imprecise because of approximated data. The most insecure value for the absorption chiller is the temperature in the tank. The cooling effect is based on the temperature in the tank which has been set from recommendations and then controlled through simple programming in Excel to make the temperature react as close to real case as possible. The temperature out from the tank was set to be 90°C which can change if the temperature is better calculated. The temperature also determines when the sp/abc-system is working or not. This has been calculated from the temperature in the tank. Excel which has been used to calculate the temperature has got limitations in the abilities to make exact calculations with programmed regulation. This gives insecurities to the reliability of the calculations and it can therefore not be treated as exact percentages, more like estimations.

Other data that are insecure are the approximated electricity consumption and efficiency for the heat exchangers. The electricity consumption is approximated from a system with four pumps and the required effect changes widely with the length of the pipes, height from the lowest point to the highest in the system and the efficiency of the pumps. The efficiency for the heat exchangers is set to be a constant temperature difference of 5°C. This can however be different in the aAa 2 kW from ECONICsystems.

Table 9. Overview over the most important mean values with standard deviation for 8760 values.

	Solar radiation*	Heat loss from the solar panel	Heat loss from the tank	COP for the absorption chiller	Tank temperature	Outdoor temperature
Mean	308.2 W/m^2	80.0 W	91.1 W	1.37	91.2°C	25.7°C
Std.	242.8 W m^2	5.61 W	16.21 W	0.26	11.97°C	2.99°C

*4326 values.

4.8.8 Problems with Applying the Sp/Abc-System in Practice

The implementation of a sp/abc-system might also result in other problems except for the ones already mentioned. The absorption chiller is filled with ammonia which may leak out if one of the pipes brakes. The ammonia is easily detectable by the smell but can be lethal in high concentrations. The other drawback compared to a normal air conditioning system is that the whole system needs safe and complex installation. It will need the absorption chiller, a cooling device or system, a cooling tower for the back cooling of the condenser and the absorber and a solar panel system. The cooling tower and solar panel need to be placed outside the house on a safe place where they will not be damaged. The cooling device will have to be placed in the room that is to be cooled.

Another problem in the proposed system is that the water in the tank rapidly reaches 100°C during sunny days even though the use of energy from the tank is high. This leads to that the water starts boiling and no more effect can be taken up by the water. The water will just vaporize out from the unpressurized tank and new water will have to be added. The system could probably work better with a higher pressure in the tank so that the water could reach higher temperatures before boiling. Another solution could be to use oil that does not have the problem with boiling. Oil for the solar panel is however more expensive.

Something which is very important for the accumulator tank in the sp/abc-system is the thermal insulation. The solar panel system works with higher temperatures compared to the systems designed for tap water heating. The mean temperature in the system is 90°C and the heat losses from tank and pipes increase linearly with the temperature. It can therefore be economically profitable with more insulation than for the regular solar panels sold for tap water purposes. It is also more important to insulate the pipes in the system from heat losses.

The solar system is very sensitive to outer forces, especially the vacuum pipes in the solar panel. The glass pipes can easily be crushed by a stone or other hard objects and the vacuum pipes get punctured. This is always a risk but might be even higher in the area of Guasmo that has problems with poverty and crime. The panel needs to be placed on the roof with 30°

inclination clearly visible from the street and within rage for thrown objects. The placement of the solar panel on the roof might lead to other problem than vandalization. The tank contains about 200 litres of water and therefore has a weight of more than 200 kg. The standard house in Guasmo has a 1 mm thick steel roof that will not cope with the high pressure from the tank. This means that the roof needs to be supported in someway to be able to hold up the solar panel system.

4.9 Future Prospects

The investigation shows that the climate in Guayaquil is appropriate for a sp/abc-system. It also gives a rough estimation on how large the solar panel should be. This might be good background information for future studies in applying a sp/abc-system on a house, but some things like regulation simulation should be investigated further before constructing a pilot test. The calculations should be run in a regulation program, like Simulink or Linksys, to make the calculations more precise and more focus will have to be put on how the system can be regulated. An advanced regulation system requires more expensive pumps but will lead to a more effective system. Important is also how the household should control the system.

Before the system can be recommended to anyone it needs to be tested in a pilot test to investigate how the system reacts in reality. This is important due to the high impact that the regulation has on the system. It also needs to be tested with the social habits of people and optimized thereafter.

The investment cost for the sp/abc-system is very high which probably makes it a solution more suitable for high- or middle-income housing. We therefore suggest that an investigation shall be executed for this type of housing. By introducing the technique in high-income housing the technology can be accessible and affordable for the low-income housing in the future. This is a study that would be appropriate to combine with a minor field study.

Something that can be of better use in low-income households would be if the sp/abc-system was used in refrigerators. The use of refrigerators is higher than the use of air-conditioners in the area of Guasmo and will be so for many years more. That might be have a larger environmental impact and be more profitable than the application of sp/abc-system for air conditioning. The sp/abc-system can be used for this purpose but requires higher temperatures and therefore a more effective solar panel system.

4.10 Resumen: Investigación de aire acondicionado accionado por energía solar

La investigación realizada mostró que el 5 % de los habitantes en el sector 351 en Guasmo tienen aire acondicionado, pero que al 80 % le gustaría tener un sistema de aire acondicionado en el futuro. Sí partimos de esta realidad para todo el Guasmo y para otras areas de asalariados bajos; esto implicará que en el futuro el consumo de electricidad esencial sería mucho más alto que el consumo de hoy en DIA. Por esta razón, consideramos que es muy importante investigar sistemas de aire acondicionado alternativo, que consuman menos electricidad y con esto se contribuya a un desarrollo sostenible en las areas tropicales urbanas.

En este capítulo la potencial y la aplicabilidad de una propuesta para un sistema de aire acondicionado accionado por incremento de temperatura es claro. Un sistema como este podría reemplazar a los sistemas convencionales de aire acondicionado y debido a que es accionado por el calor, derivado de un panel solar, este consumiría muy poco o nada de electricidad. El sistema examinado consiste en un panel solar de auto circulación al vacío de $4m^2$ de la compañía TechnoSol; asequible en Ecuador. Un refrigerador de absorción de 2 kW de la compañía ECONICsystems; un elemento enfriador de volumen y además una torre para extraer el calor. Este sistema como tal no es producido hoy en día pero las componentes existen, y por tanto es factible construirlo. Una imagen del sistema se ve en la Figura 40. Este experimento es solo teorético y se concentró en la solución del panel solar y del refrigerador de la absorción.

En la investigación se ha calculado el efecto medio que el panel solar puede producir. Este fue de 460 W en un promedio de un año, (ver Apéndice 10). Este efecto se ha usado después para accionar el refrigerador de absorción en dos vías. Un efecto de enfriamiento de cada vía se ha calculado para el refrigerador de absorción. Una exigencia para que el sistema funcione es que la temperatura en el tanque del acumulador del panel solar sea mínimo de 80 ℃. Los dos efectos del ciclo de enfriamiento fueron examinados en un programa de simulación por computadora, DEROB-LTH, donde se simuló una casa estándar de Guasmo, los dos efectos de enfriamiento fueron aplicados. En el último, simulaciones de la temperatura dentro la casa normal con los dos efectos de frío fueron realizados. La ilustración del programa de computador de la casa estándar puede ser vista en la Figura 44.

El sistema de refrigeración por absorción ha calculado un coeficiente de prestación de 1.3 (COP). Esto nos daría un efecto continuo de enfriamiento de la absorción refrigerada de 600 W, el cual fue uno de los dos efectos de refrigeración que se puso a prueba en la casa estándar. El efecto en la temperatura interior fue poco, máximo de 1 °C, donde el sistema funcionó efectivamente solo la mitad del tiempo (ver figura 55 y 58). Bajo estas condiciones se tomo la decisión de conducir la refrigeración por absorción como discontinua y solo durante un tiempo corto. Sí la refrigeración por absorción fuera conducida entre las 11 a.m. y las 7 p.m., sería posible utilizar un efecto de 2000 W entre el 1º de Octubre y el 31º de Marzo y de 1400 W entre el 1º de Abril y el 31º de Septiembre en vez de los 600 W. Esta fue la segunda forma de utilizar la refrigeración por absorción y se denomino *efecto regulador de enfriamiento*. A menor tiempo de uso se obtiene mayor efecto (2000/1400 W) porque la energía se ahorra (ver Apéndice 14). Si el sistema es utilizado de esta forma, es más confiable y funciona mejor, 80 % del tiempo (ver Figura 53). Esta forma de uso es más racional, porque el sistema tendría momentos de punto de hervor menos veces, si el efecto mayor es retirado del sistema, especialmente cuando la radiación solar es más alta. Como es obvio, cuando la temperatura del sistema llega a 100 °C, este no puede absorber más energía si el almacenamiento no es posible. Con el *efecto regulador de enfriamiento*, la temperatura dentro de la casa estándar fue reducida a un máximo de 4°C (ver Figura 55 y 58). El sistema también fue probado en el cielo raso de la casa estándar, produciendo un enfriamiento de 2°C, para ambos casos, con o sin el *efecto regulador de enfriamiento.*

Finalmente la investigación hizo un cálculo de costos para el sistema propuesto, aire-acondicionado accionado por energía solar, considerando una longevidad de 10 años. El resultado mostró un costo de inversión y producción de mínimo $ 4000, siendo al menos dos veces mayor que un sistema tradicional de aire acondicionado, con el mismo efecto y el mismo tiempo del trabajo.

En conclusión podemos decir que el sistema examinado no es apropiado para los habitantes en Guasmo, asalariados bajos. Pero el sistema tiene buen potencial para el futuro, pues significativamente consume menos electricidad, solo 150 W. Desarrollar una sistema como éste, contribuye a un desarrollo más sostenible en áreas urbanas tropicales, donde se necesitan sistemas mecánicos que regulen el clima dentro de las casas.

5 Conclusions

5.1 Investigation of Possibilities for Biogas

It can be concluded that there are very good prerequisites for implementing large scale biogas production in Guayaquil but it is harder to find good reasons to do it specifically in Guasmo. Initially it was thought that there was a possibility to produce urban biogas on a small scale and that it would improve the standard of living in poor urban areas like Guasmo. The inhabitants could use their own organic solid waste to produce biogas for cooking. They would have free gas, it would be more environmentally friendly than the present use of liquefied petroleum gas (LPG) and it could even facilitate the garbage collection system which often is a problem in poor urban areas. However it was soon realized that the production of organic solid waste from a family in Guasmo, measured to be 1.2 kg/day, was not enough raw material to produce the amount of biogas the family needed for cooking. If the biogas production is assumed to be the theoretical maximum the amount of organic solid waste would still only cover about 10 % of the family's gas consumption. There were also other difficult problems with small scale urban biogas production like; where to put effluent wastewater from the process, low reliability of the production of biogas and few if any suitable systems for the production are available on the market. If biogas is to be produced the only option would be to collect the organic solid waste and treat it in a large scale biogas plant, but then many of the advantages of the initial idea are lost.

If a large scale biogas plant was implemented it clearly is possible to produce a considerable amount of energy. By collecting the organic fraction of the municipal solid waste (OFMSW) from the 33000 households in Guasmo during one year and treating it anaerobically in a Dranco biogas plant instead of putting it on a landfill which presently is done, 7.26 GWh can be produced. 7.26 GWh of biogas is enough gas to supply about 2100 Guasmo households with cooking gas for one year. This can be a good way for the municipality of Guayaquil to implement sustainable development in the future.

There are two ways of using the biogas if it was produced. One is to fill it on the presently used LPG tanks and sell it like LPG is sold now for cooking. The other is to transport the gas to the Machala power plant south of Guayaquil by pipe or truck and mix it with the natural gas used there to produce electricity. One problem with filling biogas on the tanks presently used for LPG is that only one third of the energy will fit into the tank, it would however give the greatest environmental benefits. If the biogas was to be transported to the Machala power plant and mixed with the natural gas there to produce electricity, the power plant would need less natural gas. This means that the payback time of the biogas plant would depend on the production cost of the natural gas. Even though it is in this case harder to foretell the payback time it probably is the best use of the biogas because there would not be the problem with that the LPG tanks would contain less energy if they were filled or mixed with biogas.

Guayaquil seems suited to have biogas production and would have many advantages with it such as; a smaller volume of waste would be put on the landfill, smaller leaches of methane from the landfill, a more energy effective biogas production due to the warm tropical climate, smaller emissions of CO_2 from the Guayaquil region, a more independent energy supply and that the produced compost can be used in farming close to the city. However there are two major problems with implementing biogas production in Guasmo or Guayaquil. One is that the price of the biogas would have to be at least $ 0.17/kWh, 3 times higher than the present unsubsidized LPG price, if the biogas plant was to break even annually. If the biogas was sold for the present unsubsidized LPG price, $ 0.05/kWh, the undiscounted payback time for the plant would be 26 years, 6 years longer than the assumed economical lifetime of this project. That the lowest possible price which can be taken out for the biogas is much higher than the present LPG price is a large problem for implementing a biogas plant in Guasmo. But since a biogas plant project both leads to CO_2 emission reductions and to sustainable development the project is highly suitable to apply for additional financing in the form of certified emission rights from the clean development mechanism, which is a part of the Kyoto protocol. There are already several other projects in Ecuador that have received this support.

The second problem is that a source separation system with one organic and one inorganic fraction would have to be implemented in the part of the city which the biogas plant is to use as a collection area. Suitable areas to try out such a system on would be a medium or high-income area or maybe even the gated communities because they are all well organized on the infrastructure level. It would give easy access for collecting vehicles to the waste. To create an incitement large enough to implement such a system one possible way could be to have some kind of bonus system. For example the households in an area that participate in source separation of the household waste could receive a lower price on electricity or not have to pay for garbage collection. But the question is if this is enough.

Another method to mitigate both the economic problems of biogas production, create incitements for source separation and involving Guasmo in large scale biogas production would be to use Guasmo as collection area. This is based on the assumption that the government wants to phase out the present national gas subsidy system. The purpose of the LPG subsidy system is to improve the financial situation for the poor but it now benefits also the rich and costs the government $ 400 million annually. It is highly plausible that the government wants to reduce subsidies because the subsidized LPG is now so cheap that it is used to drive cars on, heat pools and even smuggled to neighbouring countries like Peru. And what if the international gas price was to increase? Assume that the gas subsidies were taken away. Then the inhabitants of Guasmo who participate in source separation can continue to receive the present governmental subsidy on gas. This would mean a financial incitement of about $ 20/month which is 1/5 of the minimum monthly salary and therefore a great reason to source separate for inhabitants in a low-income area. Additionally it would be a subsidy system that only benefits those who really need it and it might even help improving infrastructure in poor areas because more transports would pass through them. If this system was implemented a more sustainable development and living situation improvements in a poor urban area would be achieved at the same time. The money that the government saves on phasing out the LPG subsidies could be used to support municipalities or companies that want to invest in biogas plants. A capital investment of around $ 10 million would be needed for a biogas plant that handles OFMSW from all the 33000 households of Guasmo.

Finally it is concluded that making environmental improvements in low income areas in developing countries might seem easy, there are a multitude of environmental issues to work with e.g. waste water treatment, garbage treatment, sustainable energy production, destruction of forest and wildlife and so on, so surly something can be done. But it is very hard because the alternative has to be economically viable as well since it is competing with basic human needs like putting enough food on the table and giving your children an education. Also modern solutions to some of the environmental issues mentioned above are large scale projects that benefit the individual little and it is almost always the individual that needs benefits in low income areas of developing countries.

5.2 Investigation of Solar Powered Air-Conditioning

First of all it should be said that the solar powered absorption chiller-system (sp/abc-system) is a less practiced technology than the technology to produce biogas from organic material. It has therefore been more difficult to make accurate calculations based on established methods. The system works by collecting heat with a solar thermal panel and using this heat in an absorption chiller to produce chilled air. Because the system is run on heat it only needs little or no electricity.

It has clearly been shown that the system works and can cool with a constant effect of about 600 W 24 hours a day all year round in the climate of Guayaquil. But if the sp/abc-system is run this way the reliability is a problem and the system malfunctions 50 % of the time. The best way to regulate this kind of system would be to only run it during the hot hours of the day and use the low outside temperatures to cool the buildings during the nights through natural ventilation. If the system is run in the daytime between 11 a.m. and 7 p.m. a cooling effect of 2000 W can be taken out during the period October 1st to March 31st and 1400 W can be taken out during the period April 1st to September 31st. This might seem strange but the hot and rainy winter from November to March actually has more sun as well because the rains normally start in the afternoon and the mornings have clear skies. If the system is used in this way the reliability is better and malfunctions only occur 1/5 of the time. The improved reliability of the sp/abc-system when run with 2000/1400 W during daytime can also be seen if the temperature in the accumulator tank is compared for both the modes of regulation during a longer period of time. For example in February, a hot but cloudy month, the temperature in the tank drops below 80°C, which is the temperature where the system stops to function, almost every day if an effect of 600 W is taken out 24 hours a day, but when 2000/1400 W is taken out from 11 a.m. -7 p.m. the temperature in the tank only drops below 80°C nine times during the whole month.

Moreover it can also be concluded that since a cooling effect of 2000 W actually can be taken out from the system at least during part of the year and that the maximum cooling effect given from the manufacturer of the absorption chillers is 2000 W the solar panel area of 4 m^2 seems to be right. If the system is applied on a normal Guasmo house and run 11 a.m. -7 p.m. the last week of January (25th-31st) with 2000 W the cooling effect cuts off the midday temperature peaks with about 4°C. However the indoor temperature varies greatly depending on what type of roof the normal house has. In a normal Guasmo house with ceiling the temperature tops varies between 31 and 29°C for the last week of January and without the ceiling the temperature tops varies between 33 and 31°C for the same week. It is therefore concluded that the house with ceiling has the indoor climate with the lowest midday temperature peaks and is preferable, but it is harder to say in which case the cooling effect has the most effect on the temperature. If the effect required to cool the indoor temperature to 26°C is studied in both the cases it can be seen that the house with ceiling needs about 1000 W lower cooling effect to reach this temperature and therefore is more favourable.

More work is needed on the issue of regulating this kind of system though. Because from trying out only these two ways of regulation; constant outtake of 600 W and 8 hour daily outtake of 2000/1400W. It has been shown that the maximum cooling effect which can be taken out from, and the reliability of, the system changes greatly if the outtake is constant or only during the daytime periods. Probably the most effective regulation would be with a simple PID-regulator that measures the temperature in the accumulator tank and is connected to the electrical pumps that control the flow in the system and stops the flow out from the tank if the temperature drops too low. The types of tests that are required to be done to find the best way of regulating the system can be done in a program called Simulink, which is a Matlab application. In this program a model of the system can be set up and simulations with different parameters for the regulation can be run to find out the maximum cooling effect which really can be taken out from the system and the systems reliability.

After this has been done the studies of this system could be taken even further if a pilot model was constructed. This could be done at Universidad Catolica de Guayaquil and the students can help assembling the system and run tests. If the pilot tests show positive results the system can be tested on a real house. What has to be tried out in these pilot tests are; the type and detail for the regulation but also the practical installation and interconnection of the parts of the sp/abs-system, the thickness of the insulation of the tank, the volume of the tank, the actual COP of the system and the way to apply the cooling on the volume that is to be cooled. Finally it should also be said on this subject that ECONICsystems are looking for partners to try out their pilot absorption chiller models on. This could be a way of realising a pilot model of a sp/abc-system.

The environmental benefits from using this type of climate regulation system instead of traditional air conditioning devices are that the electricity consumption in the area would decrease. The electricity in the area is produced in the Machala factory from natural gas which is a fossil source. A decrease in electricity consumption would therefore lower the emissions of CO_2. Lower electricity consumption would also lead to fewer power cuts and a smaller need of electricity imports from Colombia in the future. Using sp/abc-system instead of traditional air conditioning systems could also lower the use of freon which still is used in many cooling circuits in the whole of South America and is a problem in this part of the world.

According to the economic calculations that were done for the sp/abc-system during its lifetime of ten years it has a minimum cost of $ 4000 which is double the cost of a conventional air conditioning system over the same period. It is therefore concluded that the sp/abc-system has small applications in the low-income area of Guasmo. It should be pointed out though that for the sp/abc-system the cost is a one time investment cost because it thereafter runs almost for free whereas for the conventional air conditioning system the cost mainly is mainly made up of the cost of electricity and comes after the initial investment. Anyway the initial cost and complexity of the sp/abc-system makes it unsuitable for Guasmo, something which is very unfortunate because many households in that area have poor indoor climates that need to be improved.

However there are other simple and cheap actions that can be taken to improve the indoor climate there. These can for example be; constructing a ceiling in both concrete hollow block and bamboo houses, painting the roofs white or improving the natural ventilation especially in concrete block houses. Even though the sp/abc-system generally has no applications in Guasmo it has lots of applications in middle- or high-income areas that can afford the high initial investment and it is a very interesting alternative to traditional air-conditioners when trying to develop a future sustainable urban development in tropical areas which need active indoor climate regulation.

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7 Appendices

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Appendix 1: Questionnaire

Cuestionario

El objetivo del cuestionario es aclarar como se da prioridad a cuestiones de energía y tambien cuánto dinero se gasta en energía por ejemplo electricidad y gas. La meta del formulario es documentar el uso de la energía y hacer posible una investigación seguida de la posibilidad de introducir fuentes de energía que proteja el medio ambiente y reduzca el gasto familiar en pago de energia. El cuestionario tiene una duración de 15 minutos. Muchas gracias por su ayuda, es muy importante. Por favor solo una respuesta por cada hogar. Hay mas información sobre quienes hacen el cuestionario en la utlima pagina.

*Marque la respuesta con un **X** en el cuadro que prefiera o escriba en la linea.*

1. ¿Sexo?

☐Masculino ☐Femenino

2. ¿Edad?

☐Menor de 20 años ☐20-40 años ☐41-60 años ☐Mas de 60 años

3. ¿Cuántas personas viven en su hogar?

Total_____ Adultos______ Niños______

¿Cuántas familias viven aqui?_____________

4. ¿Tiene usted un techo?

☐ Si ☐ No

5. ¿Tiene usted aire acondicionado en su hogar?

☐ Si ☐ No Si su respuesta es NO, por favor continúe con la pregunta 6.

¿Que efecto (W) tiene el aire acondicionado? __________________

¿Cuánto tiempo usa usted el aire acondicionado?
☐ Siempre ☐ 12 horas ☐ 6 horas ☐ 3 horas ☐ 1,5 horas o menos

6. ¿Tiene usted agua caliente en su hogar?

☐ Si ☐ No

Si tiene agua caliente, ¿comó calienta el agua?
☐ Directo en la ducha con un boquilla eléctrica ☐ Otra, comó?___________________

Cuántas veces se ducha usted cada día?
☐ Pasando un día ☐ 1 vez ☐ 2 veces ☐ 3 veces ☐ Mas

Cuántos minutos se ducha usted cada vez?
☐ 5 minutos ☐ 10 minutos ☐ 15 minutos ☐ 20 minutos o mas

Cuándo se ducha usted en el día?
☐ en la mañana ☐ al mediodía ☐ en la noche

7. ¿Tiene usted una cocina de gas?

☐ Si ☐ No, otro ___________________ Si su respuesta es NO, por favor continúe con la pregunta 8.

¿Cuánto tiempo diario se usa la cocina en su casa?
☐ 10 minutos o menos ☐ 30 minutos ☐ 1 hora ☐ 2 horas ☐ 3 horas o mas

¿Le gustaria tener una cocina eléctrica? ☐ Si ☐ No ☐ No se

¿Cuántas veces al mes compra usted un nuevo recipiente con gas?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 o mas ☐ No se

¿Estaria usted dispuesto a utilizar biogas producido de desechos de basura doméstico? ☐ Si ☐ No ☐ No se

¿Estaria usted dispuesto a botar la basura domésticos en dos lugares para usar el biogas para cocinar?
☐ Si ☐ No ☐ No se

Biogas es un gas producido por materiales organico por ejemplo cáscara de frutas. Biogas es como gas normal pero no es derivado del petróleo y no afecta el clima.

8. ¿Qué artículos tiene usted en la casa?

☐ Focos o lamparas ☐ Televisor ☐ Radio ☐ Refrigerador
☐ Congelador ☐ Cocina electrica ☐ Horno microondas
☐ Computador ☐ Máquina lavaplatos ☐ Lavadora
☐ Ventilador ☐ Otro, cual?_________________

Cuántos ventiladores tienen ustedes en su hogar?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 o mas

Cuánto tiempo usan ustedes los ventiladores al día?
☐ 1 hora ☐ 3 horas ☐ 6 horas ☐ 12 horas ☐ Siempre

¿Cómo siente la ventilación en su vivienda?
☐ Nada ventilada ☐ Poco ventilada ☐ Ventilada
☐ Bastante ventilada ☐ Muy ventilada

9. ¿Cuánto paga usted para la energía cada mes?

Gas _________________________________

Electricidad ______________________________

☐ No se, otra persona en la casa paga.

10. ¿Qué piensa usted de estos cosas?

¿Le gustaria comprar aire acondicionado en el futuro?
☐ Si ☐ No ☐ Ya lo tengo
Si su respuesta es Si, cuándo ☐ En un año ☐ Dos años o mas

¿Le gustaria tener agua caliente en el futuro?
☐ Si ☐ No ☐ Ya lo tengo

11. Clasifique los siguentes artículos según la importancia que tienen en su vida diaria, indique del 1 a 6, donde 1 es lo más importante.

☐ Agua caliente ☐ Ventilador ☐ Luz
☐ Nevera y congelador ☐ Televisor ☐ Aire acondicionado

12. ¿Comó siente la temperatura en su vivienda en invierno?

☐ Nada agradable ☐ Poco agradable ☐ Agradable
☐ Bastante agradable ☐ Muy agradable

¿Cómo siente la temperatura en su vivienda en verano?(mayo-noviembre)
☐ Nada agradable ☐ Poco agradable ☐ Agradable
☐ Bastante agradable ☐ Muy agradable

13. ¿Cuántas personas estan en su casa en un día normal? marca con un numero.

8-11 de la mañana________personas 11-2 de la tarde ________personas
2-8 de la noche________personas 8 de la noche-7 de la mañana________personas

Somos dos estudiantes de ingeneria de medio ambiente de Suecia y escribimos la tesis sobre energias renovables en Guayaquil. Este cuestionario es para recolectar datos para el ensayo que va a terminar en febrero. Si ustedes tienen preguntas o quieren conocer el resultado por favor ecribir al e-mail.

Per Lundqvist — perlu81@hotmail.com
Ulf Arfwidsson — w01ufa@student.lth.se

Observaciónes

14. ¿Tipo de vivienda?

Vivienda de 1 planta ☐ Edeficio con departemiento ☐

☐ Caña
☐ Bloque sin enlucir.
☐ Bloque enlucido
☐ Bloque enlucido con acabado
☐ Otra Si tiene otra, ¿comó es? ______________________

15. ¿Superficie de la vivienda dentro del terreno?

____

16. ¿Qué tipo de techo tiene?

____

17. ¿Parece la vivienda buen ventilada?

☐ Nada ventilada ☐ Poco ventilada ☐ Ventilada
☐ Bastante ventilada ☐ Muy ventilada

18. ¿Otras observaciónes importantes, color?

____

____

Appendix 2; Calculation of the mean LPG use in Ecuador

In this appendix the mean LPG consumption for residential use will be calculated. By residential use the gas used for cooking is intended.

$$Q_{household} = \frac{Q_{LPG,Ecuador}}{n_{housholds,Ecuador}} = \frac{m_{LPG,tot} \cdot H_{LPG}}{pop/S}$$

$Q_{household}$ = Consumed LPG for cooking by one household

$Q_{LPG,Ecuador}$ = LPG energy use in Ecuador

$n_{housholds,Ecuador}$ = Number of households in Ecuador

H_{LPG} = Heat value for LPG

$m_{LPG,tot}$ = National residential consumption of LPG in Ecuador

pop = Population in Ecuador

S = Mean number of persons per household in Ecuador

$Q_{LPG,Ecuador}$ = 9466.56 GWh/year

$m_{LPG,tot}$ = 684 000 tonnes/year[123]

H_{LPG} = 13.84 kWh/kg (Appendix 5)

$Q_{household}$ = 4303 kWh/year = 359 kWh/month

$n_{housholds,Ecuador}$ = 2.08 millions

pop = 13.2 millions[124]

S = 6 (Appendix 4)

$$Q_{household} = \frac{684000000 \cdot 13.84}{13200000/6} = 4303 kWh/year = 359 kWh/month$$

Important to notice is that in the value for the national residential consumption of LPG provided by the source other areas of use than cooking are probably also included. It might include all the LPG bought by private persons and some of this gas can be used for heating water, heating pools and more. This means that the calculated value of $Q_{household}$ might be higher than the true value.

[123] International Energy Agency, 2004

[124] Swedish Trade Council, 2005

Appendix 3; Results from Collection of Organic Solid Waste in Guasmo and Calculation of Mean and Total Production of Organic Solid Waste in Guasmo.

In this appendix a list of the weight of the collected samples of organic solid waste from Guasmo is displayed. There is also a list over the contents found in all of the samples.

$$\overline{M}_{OSWhouseholdday} = \frac{\sum_{k=1}^{n=39} m_{l\arg esample}}{n_{l\arg esamples}}$$

$\overline{M}_{OSWhouseholdday}$ = Mean production of organic solid waste per household and day

$m_{l\arg esample}$ = Mass of large sample number n

$n_{l\arg esamples}$ = Number of large samples = 49

$m_{l\arg esample}$ (g)					
house	Day 1	Day 2	Day 3	Day 4	Day 5
1	2180	850	200	300	700
2	650	1300	110	500	560
3	200	1300	600	1000	800
4	2100	1300	300	100	200
5	250	500	400	1100	550
6	3900	2300	5200	4000	2300
7	-	1700	1500	1300	2700
8	2300	1800	2100	800	900
9	2440	2900	2000	2200	1400
10	1900	1200	1000	600	600
sum	15920	15150	13410	11900	10710

After eliminating the five highest and lowest values from the 49 samples the mean was calculated.

$\overline{M}_{OSWhouseholdday}$ **= 1194.5 g ≈ 1.2 kg**
Std = 695 g

The total mass for the whole period was calculated to **67090 g ≈ 67.1 kg**
The total mass for day 2 to day 5 was also calculated and this was **51170 g ≈ 51.2 kg**

The annual production of organic solid waste from Guasmo was calculated with the following equation:

$$M_{OSWannualGuasmo} = \overline{M}_{OSWhouseholdday} \cdot n_{households} \cdot n_{days}$$

$M_{OSWannualGuasmo}$ =Annual production of organic solid waste from Guasmo
$\overline{M}_{OSWhouseholdday}$ = Mean production of organic solid waste per household and day
$n_{households}$ = Number of houses in Guasmo
n_{days} = Number of days in one year

$M_{OSWannualGuasmo}$ = 1.2*200000/6*365 = **14600000 kg = 14600 tonnes**

List of contents from the 49 samples:

Rice	Plantains	Potatoes	Orange	Melon	Pineapple	Banana
Pumpkin	Carrot	Water melon	Clementine	Peas	Passion fruit	Grain
Cucumber	Broccoli	Cassava	Bread	Pepper	Green salad	Flour
Onion	Coriander	Red Beat	Egg shell	Tree tomato	Chicken	Fish
Plant leafs	Radishes	Cauliflower	Meat	French-string-Bean		Avocado
Lime	Beans	Papaya				

As can be seen in the list, there were **37** components in the organic solid waste collected from Guasmo.

To control the results of mean solid waste production the table below can be used.

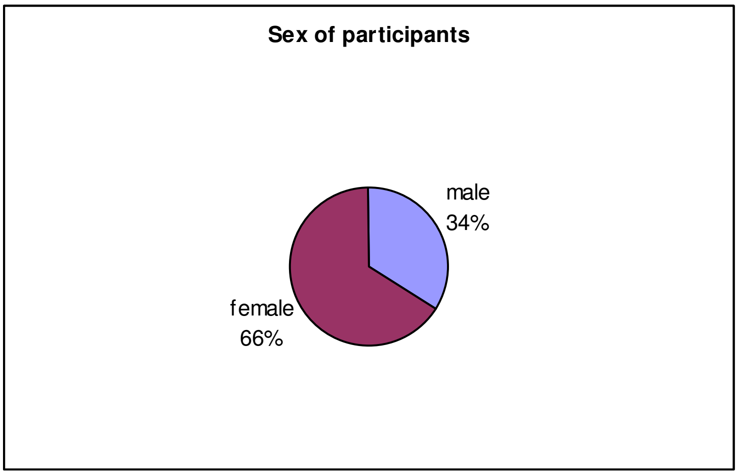
House	Nr Persons	Tot Waste(5 days)/ Household (g)	Waste per Person and Day (g/person, day)
Nr 1		4230	
Nr 2	3	3120	208
Nr 3	4	3900	195
Nr 4		4000	
Nr 5	5	2800	112
Nr 6	7	17700	505,7
Nr 7		7200	
Nr 8	8	7900	197,5
Nr 9		10940	
Nr 10	5	5300	212
Mean	5.3	6709	263.6
Std		4617.4	135.5

A control calculation is made with the data from this table and it gives a mean of 1.6 kg/ day, household which signifies that $\overline{M}_{OSWhouseholdday}$ does not differ much.

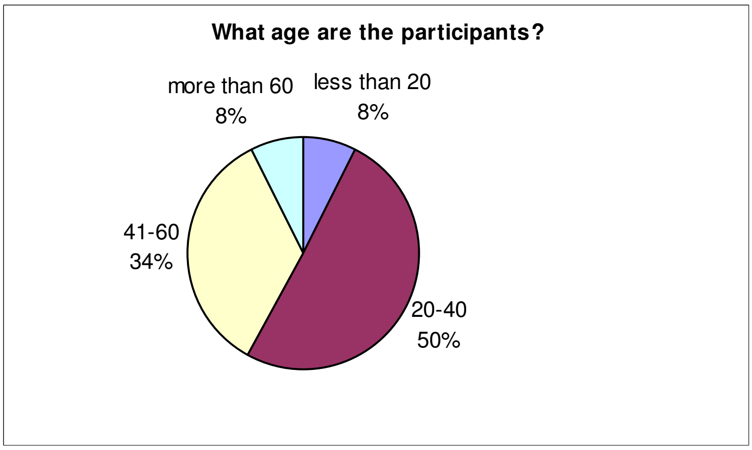
Appendix 4; Result of Questionnaire

This is the most important results of a questionnaire comprising of 18 questions regarding housing types and materials, indoor comfort, amount of gas and electricity used in the house and other facts. The questionnaire was conducted around the area of Fundación Huancavilca in the Guasmo and 105 answers were collected. In some of the questionnaires not all questions were answered but in total almost all were. This is noted below.

Result Question 1 (105 answers).



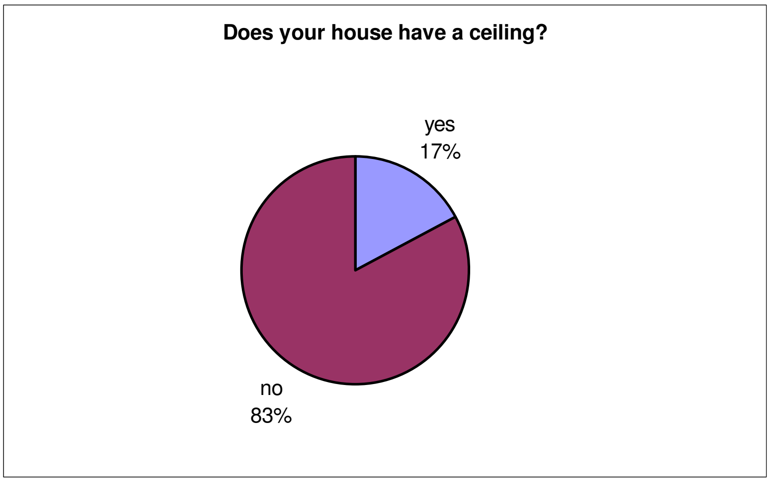
Result Question 2 (105 answers).



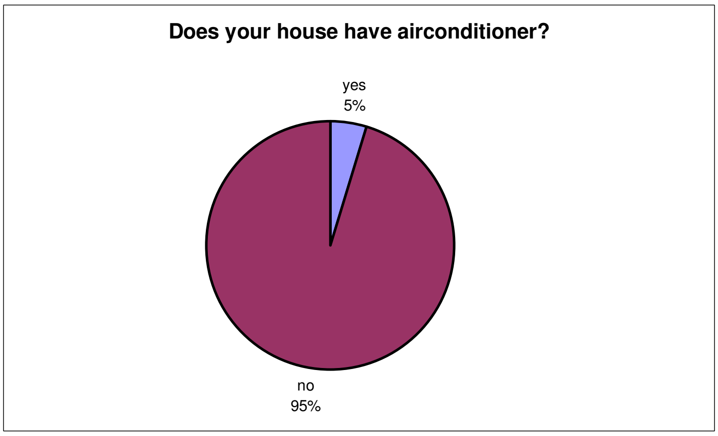
Result Question 3 (95 values).

Mean	Std.
5.737	2.027

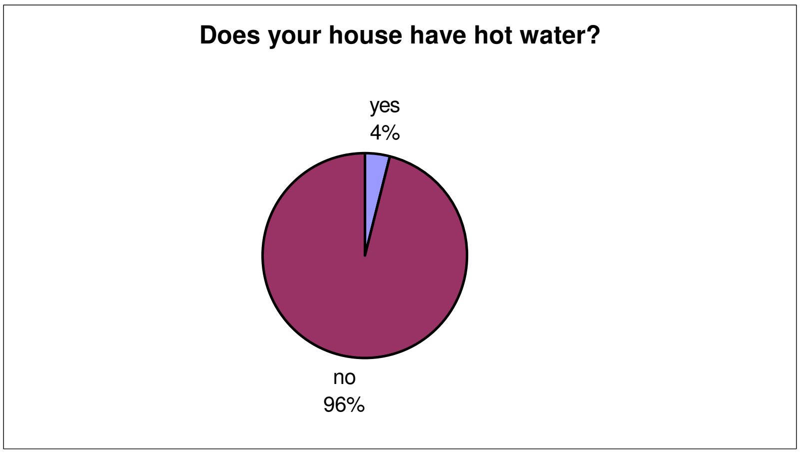
Result Question 4 (105 answers).



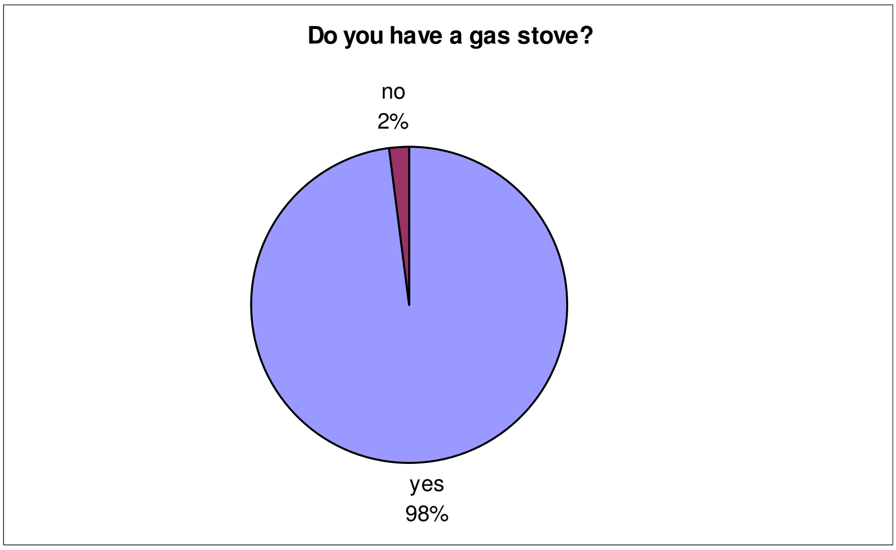
Result Question 5 (105 answers).



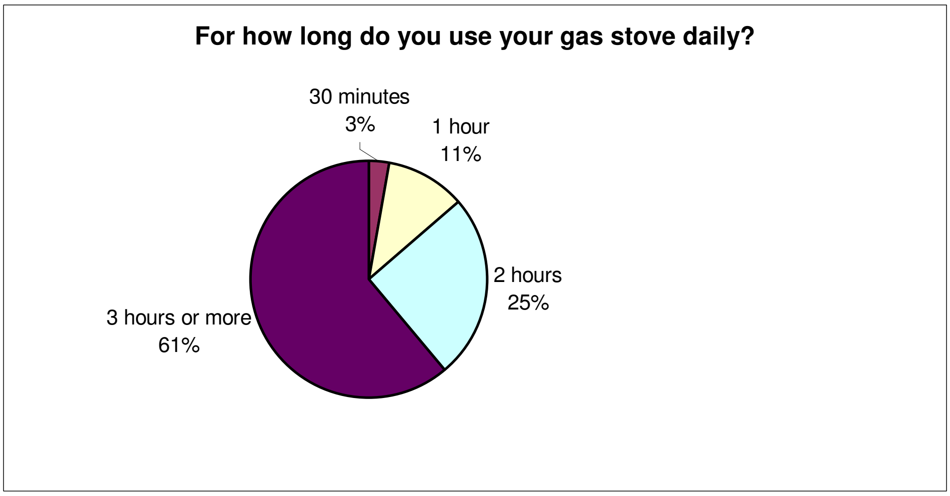
Result Question 6 (105 answers).



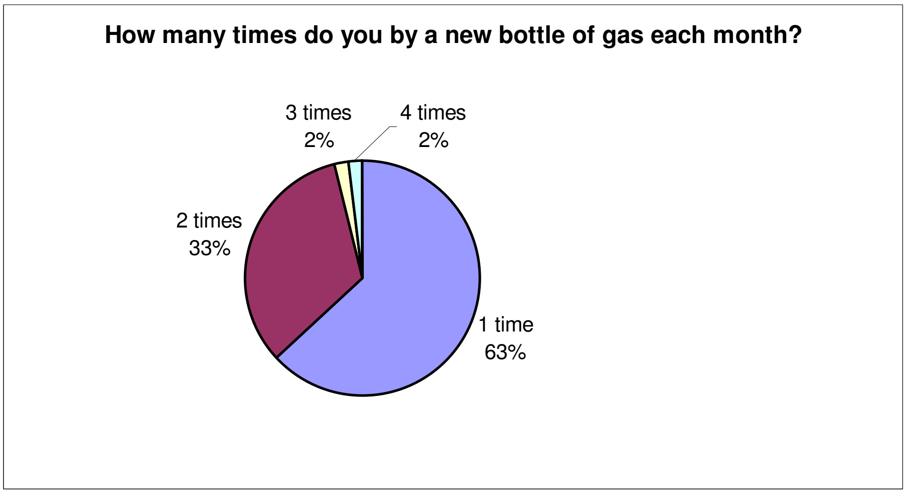
Result Question 7a (105 answers).



Result Question 7b (103 answers).

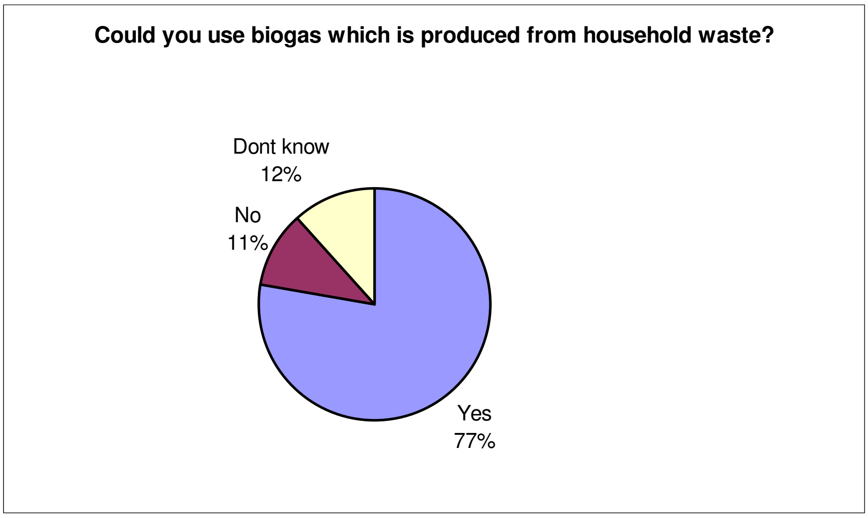


Result Question 7d (103 answers).

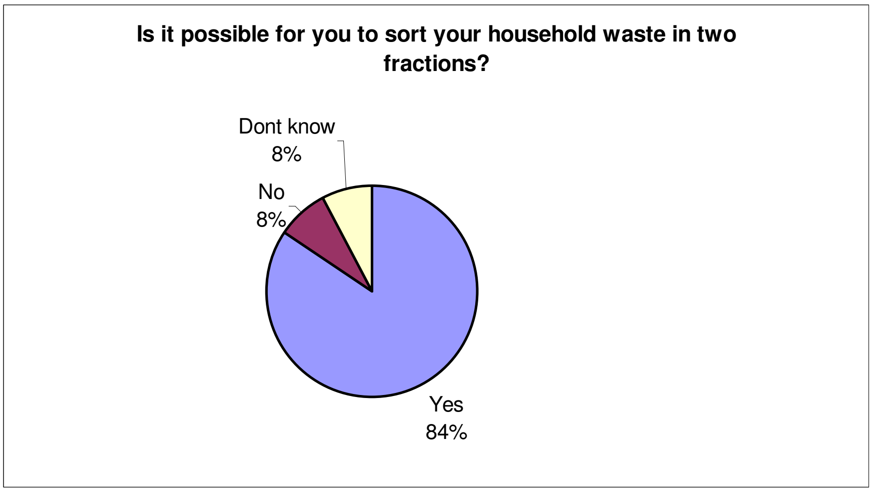


Mean 1.35 tanks/month (92 answers)
Std 0.48 tanks/month (92 answers)

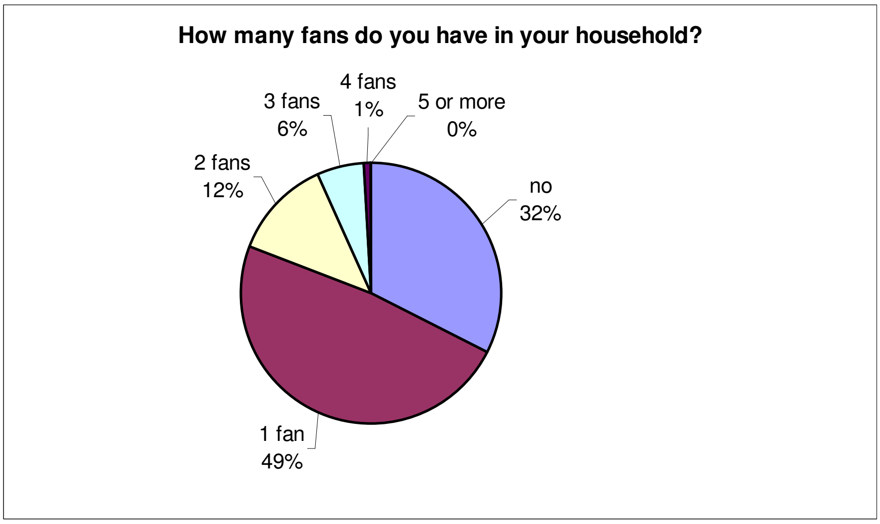
Result Question 7e (104 answers).



Result Question 7f (103 answers).

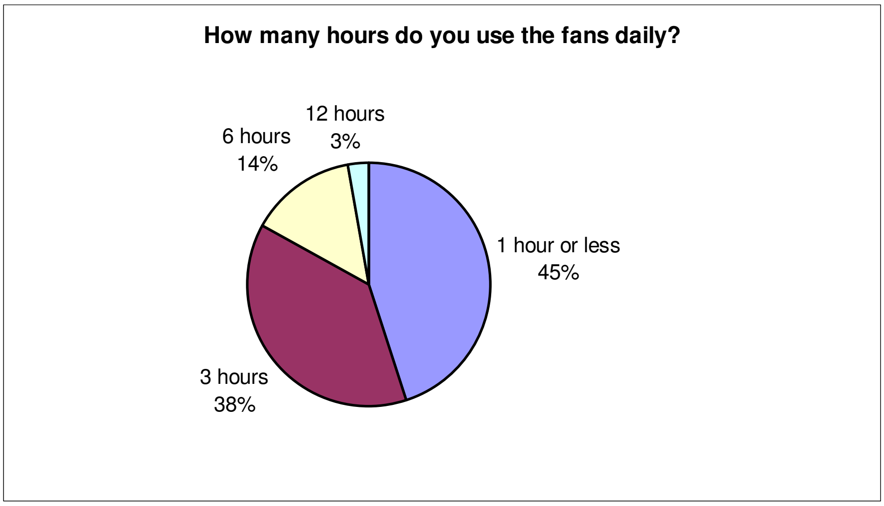


Result Question 8b (105 answers).

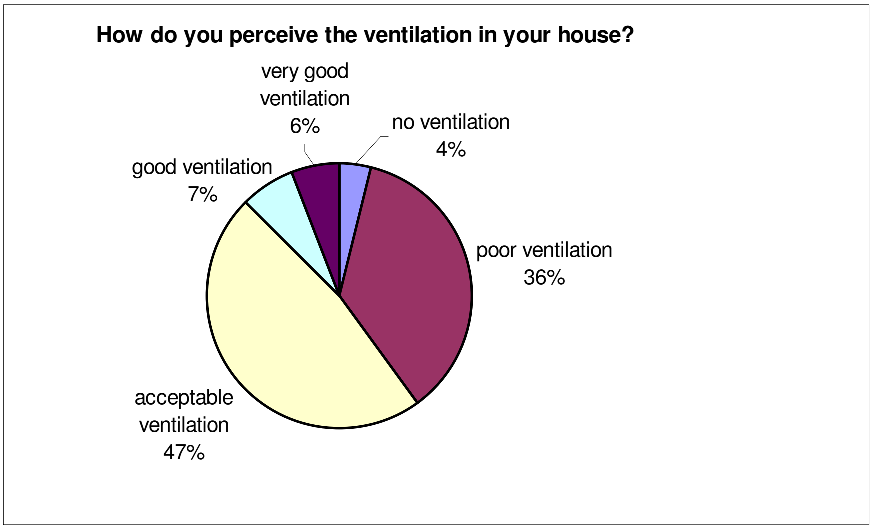


This gives that 71 persons out of 105 have fans.

Result Question 8c (71 answers).



Result Question 8d (105 answers).



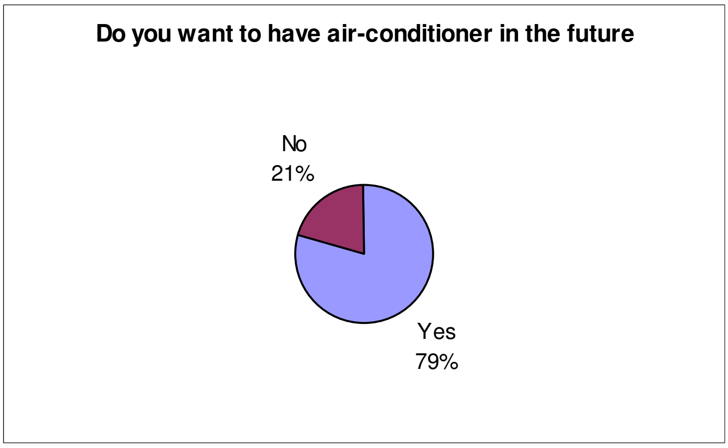
Result Question 9a. Information on how much each household pays ($) for gas each month when having discarded the 5 highest and lowest values.

Data question 9a: How much do you pay for gas every month?	
Mean	2.72
Standard deviation	1.03
Number of values	86

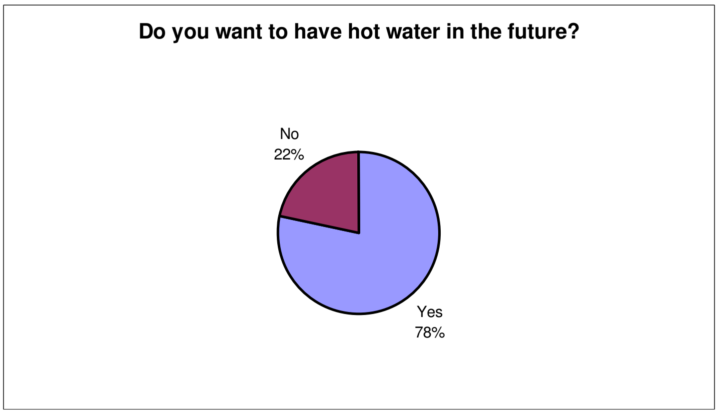
Result Question 9b. Information on how much each household pays ($) for electricity each month when having discarded the households that did not know about their consumption and did not have electricity.

Data question 9b: How much do you pay for electricity each month?	
Mean	21.2
Standard deviation	18.3
Number of values	78

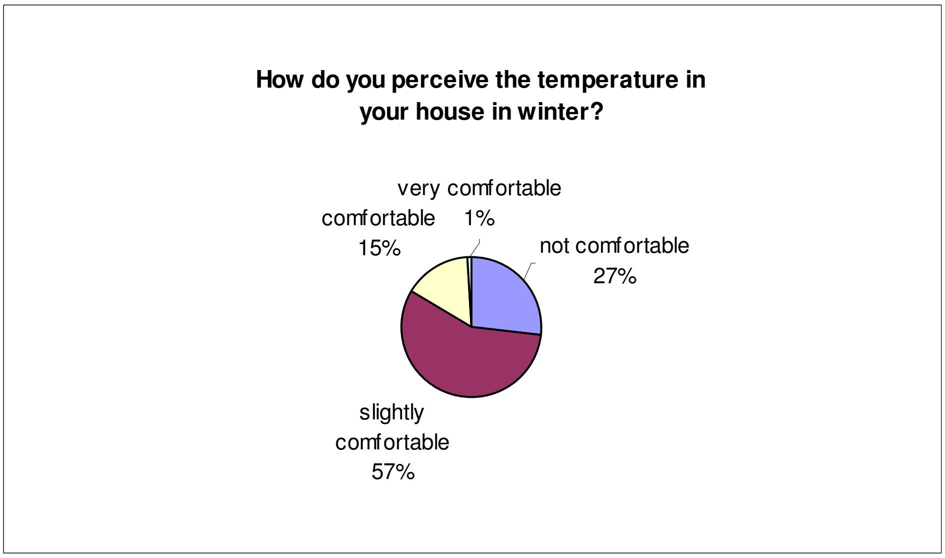
Result Question 10 a (91 answers).



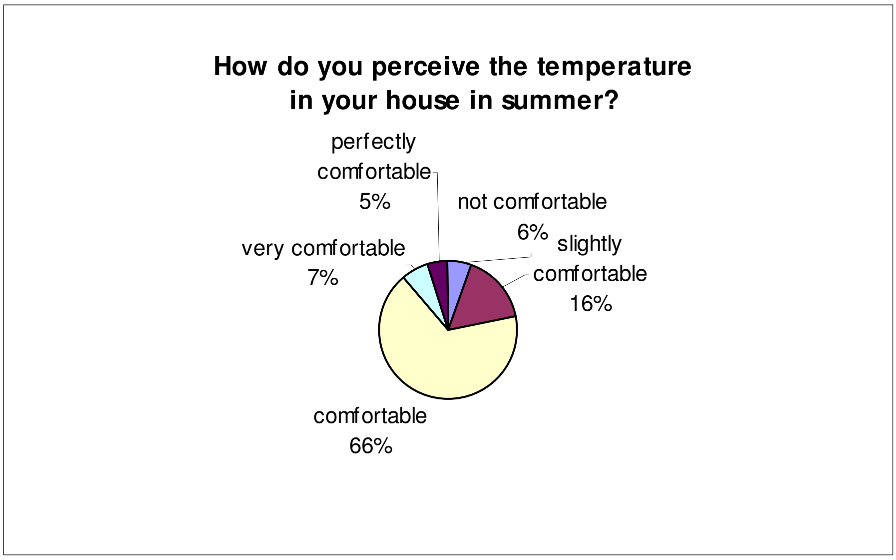
Result Question 10 c (101 answers).



Result Question 12a (104 answers).



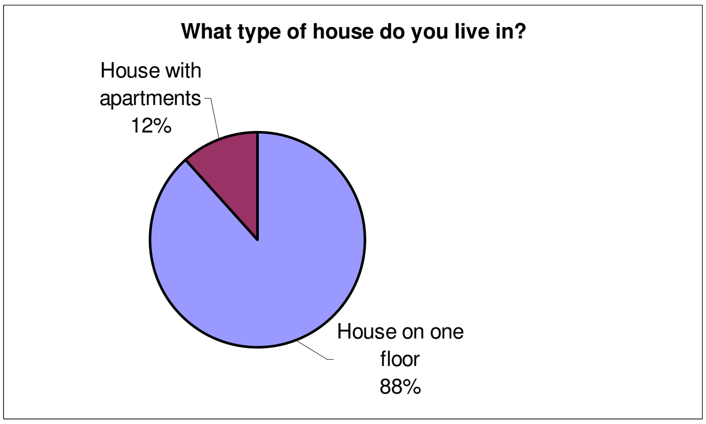
Result Question 12b (105 answers).



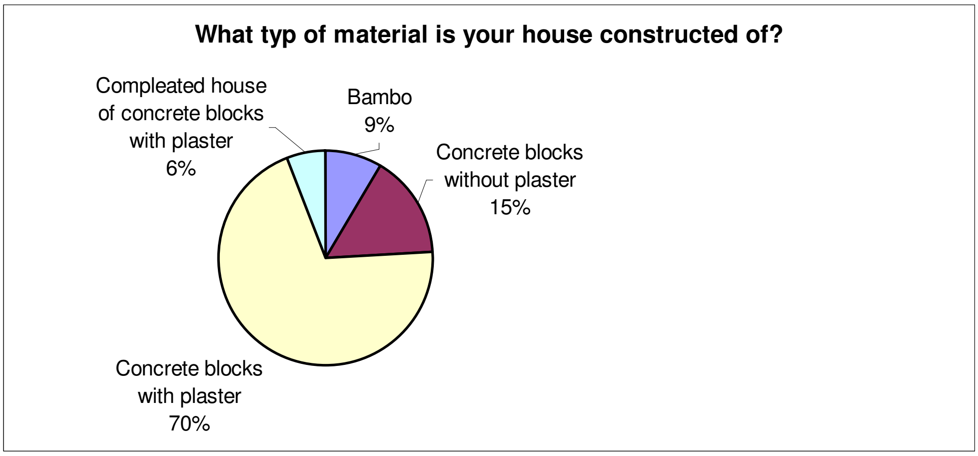
Results Question 13 (105 answers).

How many persons are in the house between the specified hours?		Exact number of persons
Morning (8 am-11 am)	3.13	3
Mid day (11 am-2 pm)	3.82	4
Afternoon (2 pm-7 pm)	4.97	5
Evening and Night (7 pm- 8 am)	5.77	6

Results Question 14a (103 answers).



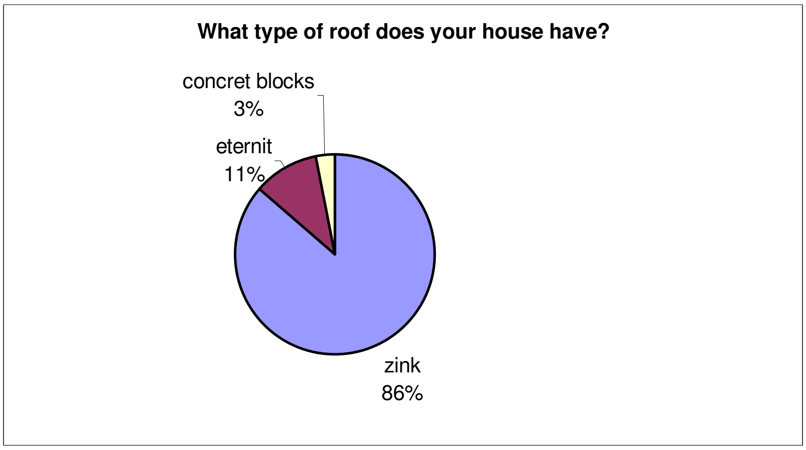
Results Question 14b (104 answers).



Question 15. Information on which area (m^2) each house that the participants in the questionnaire lived in has, when having discarded the 10 highest and lowest values due to the large variation.

Data question 15: What's the area of your house?	
Mean	85.7
Std	34.1
Number of values	81

Results Question 16 (102 answers).



Appendix 5; Calculation of Energy Content in a LPG Tank and LPG Use in Guasmo

The LPG is distributed in metal tanks in the city. They contain 15 kg gas according to the distributor Repsol. They also provided with a heat value for the LPG on 11 900 kcal/kg. [125]

$$Q_{cylinder} = m_{cylinder} \cdot H_{LPG,\text{Re}\,psol}$$

$m_{cylinder}$ = Weight of the LPG in the tank
$H_{LPG,Repsol}$ = Heat value for LPG
Conversion: 1 kcal = 1.163 Wh
$Q_{cylinder}$ = Energy in one LPG tank

Calculation with energy content from Repsol

Conversion to kWh:

11900 *0.001163 kWh/kcal=13.84 kWh/kg

Total energy content in one LPG tank
$$Q_{cylinder} = m_{cylinder} \cdot H_{LPG,\text{Re}\,psol} = 15kg \cdot 13.84kWh/kg = 207.6 \text{ kWh}$$

Control calculations

According to Repsol the LPG mix in Ecuador is 70 % propane and 30 % butane.

$H_{LPG,calc}$ Calculated heat value for LPG
$H_{propane}$ = Heat value for propane = 12.87 kWh/kg[126]
H_{butane} = Heat value for butane = 7.66 kWh/kg[127]

$$H_{LPG,calc} = 0.7 \cdot H_{propane} + 0.3 \cdot H_{bu\tan e} = 0.7 \cdot 12.87 + 0.3 \cdot 7.66 = 11.3 \text{ kWh/kg}$$

This gives that the energy in the tank is 170 kWh.

LPG use in Guasmo

As can be seen in Appendix 4 question 7 the households use 1.35 LPG tanks every month.

This leads to a mean LPG use of:

$$Q_{LPG,use} = Q_{cylinder} \cdot 1.35 = 207.6 \cdot 1.35 = \underline{280 \text{ kWh}}$$

[125] Engineer Mario Mena Aspiazu, Chief of Engineering and Maintenance, Repsol/YPF, interview, Guayaquil, 2006-11-16
[126] Wester L., 2003
[127] Lange Gas, 2006

Appendix 6; Calculation of Electrical Energy Use

Information from the questionnaire gave that every family pay in mean $ 17.6 for electricity every month. The price of electricity varies from different sources and this probably due to that every consumer pay depending on the use and area. The price is therefore calculated from two sources because the price will probably be different between the houses of the Guasmo as well.

The price according to Mercado Eléctrico Andino is different for every month and varies between $ 0.0854 /kWh and $ 0.1069 /kWh. The mean value for 2006 can be calculated to: [128]

$\frac{0.0854 + 0.1069}{2}$ = $ 0.09615 /kWh.

Calculations from the electrical bill from the house of Ana Solano:
They had a monthly consumption of 286 kWh per month and paid $ 27.31 monthly.

That gives an electrical price per kWh of $\frac{price_{electricity}}{Q_{electricity}} = \frac{27.31}{286} =$ $ 0.0955 /kWh

$Price_{electricity}$ = Price for electricity

$Q_{electricity}$ = Energy in electricity

The price of electricity is therefore assumed to be **$ 0.096** /kWh.
This gives a mean use of electrical energy of $\frac{17.6}{0.096} =$ **183** kWh /month.

[128] Mercado Eléctrico Andino, 2006

Appendix 7; Calculation of Theoretical Maximal Production of Biogas

The production of biogas varies for the different parts of the organic waste. The organic waste consists of fats, proteins, carbohydrates and other compounds like starch and fibre. The transformation rate has been elaborated to:[129]

Table 10; Biogas Production from Carbon Compounds.

Fats	0.85	m^3 methane/kg VS
Carbohydrates	0.4	m^3 methane/kg VS
Proteins	0.5	m^3 methane/kg VS
Other Carbon Compounds	0.4	m^3 methane/kg VS

The content of every waste sample was documented as percentages of the sample volume and nutrient tables were used to determine the concentration of the different carbon compounds in every grocery. In Swedish nutrient tables that were used the contents were divided in six parts. The organic fraction consisted of water, fat, proteins, carbohydrates, fibres, and trace elements sometimes noted as ash concentration. The content can be seen in Table 14. The most important groceries in the samples are shown in Table 11.

[129] Swedish Association on Biogas (SBGF), November 2004

Table 11; Table Shows the Contents in the Waste Samples.

	Approximation of mean contens. (g)																			
Waste sample	Bread	Potatoes	Plataines	Banana	Rice	Passion fr	Cucumber	Red Beat	Egg shell	Plant leafs	Avocado	Water mel	Orange	Melon	Pepper	Peas	Carrot	Onion	Grain	Cassava
1		340	340																	
2					260	390	260													
3		260	260		260			130										130		
4					1040		130		130											
5			125				100			150	100									
6	230	460			920							460								
7			510		680								340							
8		360	720		540															
9		290			290								870	870	290					
10	120				120											840				
11			90														120			
12			300	100									50							
13			400		300															
14															10		20	70		
15		110							110								110		770	
16			1200		1200	200								400						400
17			260										260				260			
18		80	400		320															
19					440															
20	180		120	60																
21		35	140		420										35		70			
22		56	336	56	56															
23				80	160		80							160			80			
24															40			80		
25		495																		
26		115	460		690	115														115
27			540		270							270								
28					630	90														
29					560								70				140			
30			60	300	60								120							
31		60															40			
32			11	44		33														
33		120	180																	60
34			240												15					
35		80						120									80			
36		520	1040		1040							260	1040							
37		150												300			150			
38		210	210	840	630															
39					600		200							800						
40			300	100																
Total weight of the single containing parts	530	3741	8242	1580	11486	828	770	250	240	150	100	990	2750	2530	390	840	1070	280	770	575
Part of tot. Waste	0,0103576	0,073109	0,161071	0,030877	0,224467	0,016181	0,015048	0,004886	0,00469	0,002931	0,001954	0,019347	0,053742	0,049443	0,007622	0,016416	0,020911	0,005472	0,015048	0,011237

The table show the weight of that specific grocery in the 40 bags of waste. The 40 bags have their own row in the table and the two last rows describe the total mass of one grocery and the percentage that makes out of the total weight.

The total amount of carbon compound in the total weight of waste was calculated with the equation below:

$$m_{grocery,tot} = \sum_{grocery} c_{grocery} \cdot m_{sample}$$

m_{sample} = specific weigh of every sample
$c_{grocery}$ = concentration that the single grocery had in the waste bag.
$m_{grocery,tot}$ = total weight of the grocery

Ex. The first grocery in the table is bread. Three bags contained bread and the first one contained 10 % bread and bag weighed of 2300 g, second 10 % and 1200g and the third 30 % where the bag weighed of 600g. The contribution of weight bread in the total amount of waste was therefore.

$$m_{bread,tot} = \sum_{bread} c_{bread} \cdot m_{bread} = c_{bread,1} \cdot m_{bread,1} + c_{bread,2} \cdot m_{bread,2} + c_{bread,3} \cdot m_{bread,3} =$$
$$0.1 \cdot 2300 + 0.1 \cdot 1200 + 0.3 \cdot 600 = 530g$$

A general content in the total amount of waste for four days was calculated from the nutrients content for each product and the concentration they had in the samples taken for this period. Only four days were used because of missing volume percentages from the first day. The nutrient concentration can be seen in Table 12 and there is also a comparison between the former calculated carbon concentration and the divided in different nutrients. The difference is about 3 % and is due to the fact that only the groceries with the highest concentrations have been included. The new concentration of the different carbon compounds was calculated with the equations below. The weight of the groceries were calculated to a new concentration $c_{grocery,tot}$. The $c_{carb.compound,grocery}$ is the concentration of one specific carbon compound for example fat in one grocery.

$$c_{grocery,tot} = \frac{m_{grocery,tot}}{m_{waste,tot}}$$

$$m_{compound,grocery} = c_{grocery,tot} \cdot c_{carb.compound,grocery} \cdot m_{waste,tot}$$

$$c_{compound} = \frac{\sum_{grocery} \left(m_{compound,grocery}\right)}{m_{waste,tot}}$$

$c_{carb.compound,grocery}$ = Concentration of the specific carbon compound in the grocery
$c_{grocery,tot}$ = Concentration of a single grocery in the total amount of waste
$c_{compound}$ = Concentration of the carbon compound in the total amount of waste
$m_{waste,tot}$ = Total weight of the 40 bags
$m_{compound,grocery}$ = Weight of the a compound from a grocery

Ex. The weight of bread was calculated to 530 g in the total amount of waste. This meant a concentration of:

$$c_{grocery,tot} = \frac{m_{grocery,tot}}{m_{waste,tot}} = \frac{530}{51154} = 0.0103$$

The concentration of for example carbohydrates in bread is 45 %.
This gives the weight of carbohydrates from bread:

$$m_{carbohydrates,bread} = c_{grocery,tot} \cdot c_{carb.compound,grocery} \cdot m_{waste,tot} = 0.0103 \cdot 0.45 \cdot 51154 = 237g$$

$$c_{carbohydrate} = \frac{m_{bread} + m_{banana} \ldots\ldots}{m_{waste,tot}} =$$

Table 12. Calculated Contents in the Waste.

Carbon Compound	Concentration
Fat	0.362 %
Carbohydrates	16.27 %
Proteins	1.639 %
Fibres	1.068 %
	19.34 %
Organic concentration	23.15 %
Diff	3.807 %

If the missing carbon concentration is estimated to have similar biogas production rate as the carbohydrates, a maximal biogas production can be calculated and is visualized in Table 13. The equation below was used to calculate the produced gas amount. The daily waste production $F_{waste,day,household}$ has been estimated to be 1.2 kg/day and household, can be seen in Appendix 3 the $R_{compound}$ is the production rate of methane for the different carbon compounds

$$V_{gas} = R_{compound} \cdot c_{Compound} \cdot F_{waste,day,household}$$

V_{gas} = Volume biogas
$R_{compound}$ = Production rate of methane.
$F_{waste,day,household}$ = Waste flow from one household per day

Table 13. Theoretically Calculated Produced Amount of Biogas.

	Weight (kg)	Methane (m^3)
Fat	0.004348	0.003696
Carbohydrates	0.1953	0.07812
Proteins	0.01966	0.009831
Fibres	0.01282	0.005128
Diff	0.01538	0.006153
Tot		**0.1029** m^3 methane /day and one household

The concentration of the contents of the waste was visually approximated and would be the volume percentage. When calculating, the concentration was equalized to weight percentage, which could be an error. The volume and weight percentage of the waste would be quite similar due to the high content of water which has a 1:1 relation.

Appendix 8: Calculation of Production and Coverage of Gas Consumption by the 2 Processes

The mean production of organic household waste in the investigated area of Guasmo is around 1.2 kg per household and day with a standard deviation of around 0.7 kg, in the Guasmo lives around 200 000 inhabitants according to INEC and the mean number of inhabitants in each household is 6 persons according to our survey investigation, see Appendix 4. This gives that the total amount of waste produced in Guasmo is 14 600 tonnes/year.

Parameters:

Molar mass ($M_{methane}$) of methane = 16g/mol
Molar mass (M_{CO2}) of carbon dioxide = 44g/mol
Temperature (T) = 273 K
Pressure (p) = 101300 Pa

The energy content in gas normally refers to Nm^3 (normal cubic meters) of gas. One Nm^3 means one m^3 at 273K and one atmosphere pressure

Lower heat value ($H_{methane}$) of methane =35.8 MJ/Nm^3 [130]
Lower heat value for biogas H_{biogas}
Amount of waste (F) = 14 600 tonnes/year
Cover ratio for the plant (C_d)
Energy of biogas produced in Guasmo/year (Q_{biogas})
Energy of LPG used in Guasmo/year(Q_{LPG})
Energy content in one LPG tank or cylinder (15 kg gas) ($Q_{cylinder}$) = 207.6 kWh (Appendix 5)
Number of tanks used by every household/year (n) = 16.2 (Appendix 4)
Number of households in Guasmo (Households) = 33 333

Valorga-process in Tilburg

The Valorga process in Tilburg, Netherlands has a biogas production rate of 80-85 Nm^3 biogas/tonne of sorted organic waste.[131] The methane concentration in the biogas is 56 % and this is used when calculating the energy content (H_{biogas}) in the biogas. A production of 80 Nm^3 biogas/tonne of source sorted organic waste is used in the calculations.

Percentage of methane in biogas ($X_{methane,Tilburg}$)= 56 %
Production efficiency ($E_{Tilburg}$) = 80 Nm^3 biogas/tonne organic waste
Produced energy from the plant in Tilburg ($Q_{biogas,Tilburg}$)

$$Q_{biogas,Tilburg} = F \cdot E_{Tilburg} \cdot H_{biogas} = F \cdot H_{methane} \cdot X_{methane} \cdot E_{Tilburg} = 14600 \cdot 35.8 \cdot 0.56 \cdot 80 =$$

$$Q_{biogas,Tilburg} = \frac{23}{3.6} = 6.4 \text{ GWh}$$

$$Q_{LPG} = Q_{cylinder} \cdot n \cdot Households = 207.6 \cdot 16 \cdot 33333 = 112 \text{ GWh/year}$$

[130] Wester L., 2003
[131] Shefali V., 2002

$$C_d = \frac{Q_{biogas,Tilburg}}{Q_{LPG}} = \frac{6.4}{112} = 5.7\ \%$$

The Dranco-process in Brecht

The Dranco-process in Brecht has a production rate of biogas of between 100-120 Nm^3 biogas/ tonne sorted organic waste. The methane concentration in the biogas is between 50-60 %. A biogas yield of 100 Nm^3 biogas/ tonne sorted organic waste and a concentration of 50 % is used for the calculations.

Percentage of methane in biogas ($X_{methane,Brecht}$)= 50 %
Production efficiency (E_{Brecht}) = 100 Nm^3 biogas/tonne organic waste
Produced energy from the plant in Brecht ($Q_{biogas,Brecht}$)

$$Q_{biogas,Brecht} = F \cdot E_{Brecht} \cdot H_{biogas} = F \cdot H_{methane} \cdot X_{methane,Brecht} \cdot E_{Brecht} = 14600 \cdot 35.8 \cdot 0.50 \cdot 100 = 26.1$$

$$Q_{biogas,Brecht} = \frac{26.13}{3.6} = 7.26 \text{ GWh/year}$$

$$Q_{LPG} = Q_{cylinder} \cdot n \cdot Households = 207.6 \cdot 16 \cdot 33333 = 112 \text{ GWh/year}$$

$$C_d = \frac{Q_{biogas,Brecht}}{Q_{LPG}} = \frac{7.26}{112} = 6.5\ \%$$

The calculation of the maximum theoretical biogas production from the waste in Guasmo gave a production rate of 103 Nm^3 methane/ day and household source sorted organic waste. (Appendix 7)

Production efficiency ($E_{Maximum}$) = 0.95 Nm^3 methane/kg organic waste
Produced energy from the plant in Brecht ($Q_{biogas,maximum}$)

$$Q_{biogas,\max imum} = 13.9 \text{ GWh/year} \qquad \text{(Appendix 7)}$$

$$Q_{LPG} = Q_{cylinder} \cdot n \cdot Households = 207.6 \cdot 16 \cdot 33333 = 112 \text{ GWh/year}$$

$$C_d = \frac{Q_{biogas,Maximum}}{Q_{LPG}} = \frac{13.9}{112} = 12.4\ \%$$

Appendix 9; Calculation of Production Cost for Biogas in Guayaquil

The biogas plant needs to be able to handle 14600 tonnes/year as is calculated in Appendix 3. It would then be suitable with a reactor that has a capacity of 20 000 tonnes/year so that there is a possibility to handle higher flows. The calculations are made for two appropriate plants, the Dranco process in Brecht and the Valorga process in Tilburg. The first calculations were made to investigate a gas price. This was calculated with the annuity method where the yearly surplus was put to 0 to calculate a gas price needed to brake even.

The Brecht plant in Belgium that was started in 1992 has a suitable process and a capacity of 20 000 tonnes/year. The capital investment cost for this plant was \$ 6.1 million. With an annual inflation of 3 % this equals to \$ 9.5 million today. This gives a current capital investment cost of \$ 465/tonne capacity.

The production rate and capital investment cost is different for the Valorga plant in Tilburg, Netherlands. The plant is also bigger and was built in 1994. The other circumstances were kept the same in the calculations. The plant in Tilburg has a capital investment cost of \$ 484 /tonne capacity.

The economic lifetime of the new plants are set to 20 years, the rate of return is set to 10 % and the cost of running the plants are assumed to be one-twentieth of the capital investment cost. The same gas production rates were used for the plants as in Appendix 8.

In the cost of running maintenance, labour and administrative costs are included. These costs are approximated for Belgium and could be lower in Ecuador. This calculation does not take into account that the plants after their economical lifetime has expired might have a rest value.

In Belgium there are also revenues from the "tipping fee" and from produced compost which the plant also sells. The revenues from tipping were \$ 120 /tonne and the compost was sold for \$ 13 /tonne and the Brecht plant produces 0.3 tonne compost/tonne input. Compared to Ecuador, the tipping fees are equalized to the fee that the households pay for the collection service. The fee is 4.5 % of the minimum salary as all the houses are assumed to be small consumers of electricity. The minimum salary in Ecuador is about \$ 100 according to Banco Mundial.[132] This is for a mean amount of waste of 158 kg per month, which gives the tipping fee to be \$ 28.4 per tonne waste.[10] The compost revenues are set to the same as in Belgium.

Annuity method

Annual yearly surplus (V) = Annuity (a) – Capital costs (C)

Annuity (a) = Revenues (I) – Annual costs

Annual costs = Labour cost (l) + Maintenance(s) + Administration (adm)

$$l + s + adm = \frac{G_{plant}}{20}$$

$$C = \frac{G \cdot r}{1 - (1 + r)^{-t}}$$ [133]

[132] SICA, Banco Mundial, 2003
[133] Persson I., S-Å. Nilsson, 2001

$$\text{Annual revenues (I)} = \text{Annual production } (Q_{biogas}) \cdot \text{Price of gas } (Price_{biogas}) + I_{tipping} + I_{compost}$$

$$Price_{tipping} = \left(1000 \big/ m_{household,month}\right) \cdot Salary \cdot fee$$

$$I_{tipping} = F \cdot Price_{tipping}$$
$$I_{compost} = F \cdot 0.3 \cdot Price_{compost}$$

$$\text{Price of gas}(Price_{biogas}) = \frac{\text{Annual revenues(I)} - I_{tipping} - I_{compost}}{\text{Annual production}(Q_{biogas})}$$

The capital investment cost was calculated with this equation

$$G_{plant} = \frac{\left(G_{then}{}^{t_{plant}} \cdot i\right)}{Cap_{plant}} \cdot Cap_{Guasmo}$$

Parameters
V = Annual yearly surplus
I = Annual revenues
C = Capital cost
G = Capital investment cost
r = Interest rate of return
t = Economical life time
a= Annuity
l = labour costs
s = service and maintenance costs
adm = administration costs
i = inflation rate
t_{plant} = years since the building years
Cap_{plant} = Capacity for the plant
Cap_{Guasmo}= Capacity appropriate for Guasmo
I_{biogas} = Revenues from biogas
$I_{tipping}$ = Revenues from tipping
$I_{compost}$ = Revenues from compost
$Price_{tipping}$ = Price for tipping
$Price_{compost}$ = Price for compost
$Price_{biogas}$ = Price of biogas
Q_{biogas} = Energy production from the plant
F = Waste flow from Guasmo

Brecht plant

$$G_{Brecht} = \frac{\left(G_{then}{}^{t_{plant}} \cdot i\right)}{Cap_{Brecht}} \cdot Cap_{Guasmo}$$

$$G_{Brecht} = \frac{\left(\left(6.1 \cdot 10^{6}\right)^{15} \cdot 1.03\right)}{20000} \cdot 20000$$

$$G_{Brecht} = 9.5 \cdot 10^{6}$$

$$0 = a - Cap$$
$$a = Cap$$
$$I - (l + s + adm) = \frac{G_{Brecht} \cdot r}{1 - (1 + r)^{-t}}$$
$$I_{biogas} + I_{tipping} + I_{compost} = (l + s + adm) + \frac{G_{Brecht} \cdot r}{1 - (1 + r)^{-t}}$$
$$l + s + adm = \frac{9.5 \cdot 10^6}{20} = 475000$$
$$I_{biogas} = 7.26 \cdot 10^6 \cdot price_{biogas} =$$
$$I_{tipping} = 14600 \cdot 28.4 = 415\ 000$$
$$I_{compost} = 0.3 \cdot 14600 \cdot 13 = 56\ 940$$

$$7.26 \cdot 10^6 \cdot price_{biogas} + 415000 + 56940 = 475000 + \frac{9500000 \cdot 0.1}{1 - (1 + 0.1)^{-20}}$$

Price$_{biogas}$ = \$ 0.15 / kWh

Tilburg plant

$$G_{Tilburg} = \frac{\left(G_{then}{}^{t_{plant}} \cdot i\right)}{Cap_{Tilburg}} \cdot Cap_{Guasmo}$$
$$G_{Tilburg} = \frac{\left(\left(17.5 \cdot 10^6\right)^{13} \cdot 1.03\right)}{52000} \cdot 20000$$
$$G_{Tilburg} = 9.88 \cdot 10^6$$

$$V = a - Cap$$
$$0 = a - Cap$$
$$I = (l + s + adm) + \frac{G_{Tilburg} \cdot r}{1 - (1 + r)^{-t}}$$
$$I_{biogas} + I_{tipping} + I_{compost} = (l + s + adm) - \frac{G_{Tilburg} \cdot r}{1 - (1 + r)^{-t}}$$
$$l + s + adm = \frac{9.88 \cdot 10^6}{20} = 500\ 000$$
$$I_{biogas} = 6.4 \cdot 10 \cdot price_{biogas}$$
$$I_{tipping} = 14600 \cdot 28.4 = 415\ 000$$
$$I_{compost} = 0.3 \cdot 14600 \cdot 13 = 56940$$

$$6.4 \cdot 10^6 \cdot price_{biogas} + 415000 + 56940 - 500000 - \frac{9880000 \cdot 0.1}{1 - (1 + 0.1)^{-20}}$$

Price$_{biogas}$ = \$ 0.21 / kWh

Pay back time

When calculating pay back time the annual revenues are calculated as before. The gas price is set to \$ 0.05/ kWh biogas, with gas production rates as in Appendix 8.

The pay back time without accounting for the interest rate of return is **26.4** years and the pay back time including the interest rate of return is very long. The payback times for the Plant in Tilburg are **32.6 years** and very long. The payback time with a doubled gas price the payback time for the Brecht plant is 11 years without the interest.

$a = I - (l+s)$

$I = I_{gas} + I_{tipping} + I_{compost}$

$I_{gas} = Q_{gas} \cdot Price_{biogas}$
$I_{tipping} = F \cdot Price_{tipping}$
$I_{compost} = F \cdot 0.3 \cdot Price_{compost}$

Without interest
$$PB_1 = \frac{G}{a}$$

With interest
$$PB_2 = -\frac{\ln\left(1 - G/a \cdot r\right)}{\ln(1+r)}$$

Parameters

PB = Payback time
G = Capital investment
a = Annuity
r = Interest rate of return
l = Labour costs
s = Maintenance
I = Revenues
I_{gas} = Revenues from gas
$I_{tipping}$ = Revenues from tipping
$I_{compost}$ = Revenues from compost
$Price_{biogas}$ = Price for biogas
$Price_{tipping}$ = Price for tipping
$Price_{compost}$ = Price for compost
F = Waste flow from Guasmo

Brecht

$$PB_1 = \frac{G_{Brecht}}{a} = \frac{9.5 \cdot 10^6}{0.835 \cdot 10^6 - 475000} = 26.4 \text{ years}$$

$$PB_2 = -\frac{\ln\left(1 - \frac{G_{Brecht}}{a} \cdot r\right)}{\ln(1+r)} = -\frac{\ln\left(1 - \frac{9.5}{0.436} \cdot 0.1\right)}{\ln(1+0.1)} = \text{ very long}$$

Tilburg

$$PB_1 = \frac{G_{Tilburg}}{a} = \frac{9.88 \cdot 10^6}{0.79 \cdot 10^6 - 500000} = 32.6 \text{ years}$$

$$PB_2 = -\frac{\ln\left(1 - \frac{G_{Tilburg}}{a} \cdot r\right)}{\ln(1+r)} = -\frac{\ln\left(1 - \frac{9.88}{0.29} \cdot 0.1\right)}{\ln(1+0.1)} = \text{very long}$$

Doubled gas price

Brecht

$$PB_1 = \frac{G_{Brecht}}{a} = \frac{9.5 \cdot 10^6}{1.2 \cdot 10^6 - 475000} = 13.1 \text{ years}$$

Tilburg

$$PB_1 = \frac{G_{Tilburg}}{a} = \frac{9.88 \cdot 10^6}{1.11 \cdot 10^6 - 500000} = 15.6 \text{ years}$$

Appendix 10; Calculation of Mean Cooling Power

The goal of the calculations is to calculate a cooling effect out from the absorption chiller. The effect out from the system is highly dependent on the solar radiation and the temperature inside and outside of the systems. Heat losses and cooling effect changes when the temperature changes.

The first step of the calculation is to calculate how much solar radiation that can be captured by the solar panel ($P_{solarpanel}$). The calculation is the total radiation (I_{tot}) multiplied with the area of the solar panel ($A_{solarpanel}$) minus the reflected radiation ($\eta_{transparancy}$):

$$P_{solarpanel} = (1 - \eta_{transparancy}) I_{tot} \cdot A_{solarpanel}$$

Second, the maximum effect out from the solar system is calculated ($P_{solarsystem}$). This depends of two parts, effect from the solar panel and heat losses. The system looses heat from many places, but the focus has been on the tank ($P_{losstank}$) and the solar panel (P_{sphl}). These two are assumed to have big heat losses compared to pipes and other places, so that these can be neglected. The amount of the heat losses depends on the insulation and the temperatures in the tank and solar panel.

$$P_{solarsystem} = P_{solarpanel} - P_{loss\tan k} - P_{sphl}$$

The effect out from the solar panel system was then multiplied by the coefficient of performance (COP) from the absorption chiller to obtain the cooling effect ($P_{coolingeffect}$). This can be seen in the following equation. All the data were calculated in vectors for the varying outdoor temperature and solar radiation. But since the simulation program DEROB-LTH only can use one value as cooling effect, a mean value had to be calculated.

$$P_{coolingeffect} = COP \cdot P_{solarsystem}$$

This is a schematic picture over the absorption and solar panel system.

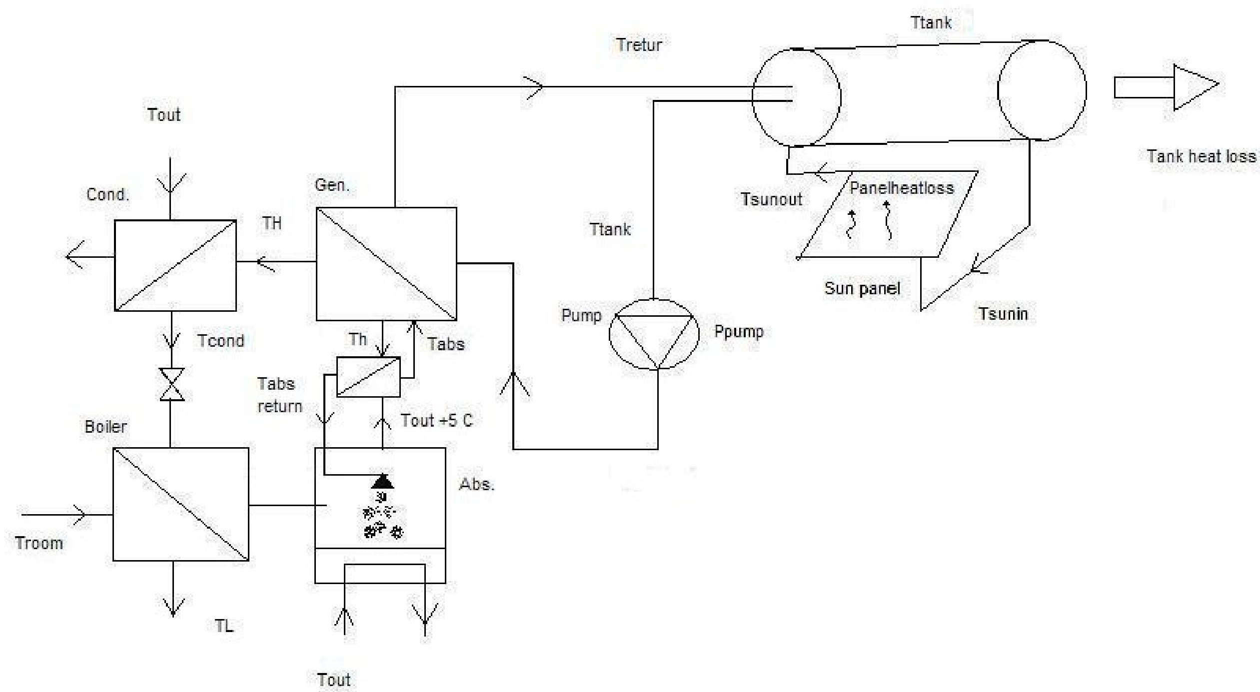


Figure 61. Schematic scheme over the solar and the absorption chiller system.

That is the general description of the calculation. The rest of the calculations will be described step by step.

First out is the solar panel effect, starting with the total radiation. The radiation could be calculated from a climate file over Guayaquil, containing solar data. The ground (I_g), diffuse (I_d) and beam radiations (I_b) were added up to the total radiation.

$$\vec{I}_{tot} = \vec{I}_g + \vec{I}_b + \vec{I}_d$$

The calculations and equations can be studied at the end of the appendix.

The total mean radiation for Guayaquil was 152.5 W/m^2, the area of the panel was 3.9 m and the refection was 2 %. This gives the mean solar panel effect of:

$$P_{solarpanel} = 3.9 \cdot 152.5 \cdot 0.98 = 583 \text{ W}$$

The solar panel has an efficiency depending on the heat loss (P_{sphl}). This can be calculated with Karlssons equation below.

$$\vec{P}_{sphl} = K_e \cdot A_{vacuumpipes} \cdot \left(T_{solarpanel} - T_{out}\right)$$

The heat loss is depending on the working temperature in the solar panel and the different temperatures can be studied in Figure 61. The calculation of the temperatures can be studied in the end of the appendix.

The area of the pipes and K_e are specific data from the solar panel. This is the calculation of the solar panel heat loss.

$$P_{sphl,\max} = 0.63 \cdot 2.37 \cdot (80 - 25.7) = 80\,\mathrm{W}$$

The solar panel does only loose heat while there is sun light and a circulation which is only 2715 hours/year. This gives a new mean solar panel heat loss.

P_{sphl}=25 W

The heat losses from the tank are calculated with heat transfer equation, regarding convection in the water inside the tank and for the air outside the tank and conduction through the insulation of the tank. The radiation from the tank is neglected as the temperature on the outside of the tank is low.

The convection coefficient on the outside of the tank is depending on the wind and the medium is air. This leads to an estimated value of $h_{out}=h_L$= 25 W/m^{2}K.[134]

The water inside the tank is assumed to be stratified in heat layers without any greater movement. This gives an estimated value of $h_{in}=h_H$=50 W/m^2 (normal values between 0.5-20 Btu/hr,ft^2,F) [135]

The insulation thickness of the tank is 55 mm (dx) and the insulation material 141B is equalized to polyethen, a material used in Swedish tanks which has a thermal conductivity of 0.038 W/Km (λ).

$$\frac{1}{k} = \frac{1}{h_H} + \frac{dx}{\lambda} + \frac{1}{h_L}$$

This leads to a calculated heat flow coefficient (k).

k= 0.66 W/m^2,K

The equation for the heat loss for the tank is the same used in the heat exchanger chapter.

$$P_{losstank} = k \cdot A_{\tan k} \cdot (T_{\tan k} - T_{out}) = 0.66 \cdot 2.12 \cdot (90 - 25.7) = 90\,\mathrm{W}$$

The maximum mean effect that it is possible to take out.

$$P_{solarsystem} = P_{solarpanel} - P_{\tan kloss} - P_{sphl} = 583 - 25 - 90 = 464\,\mathrm{W}$$

This is the effect that can be put in to the absorption chiller 24 hours daily.

The cooling effect is depending on the input temperatures in the absorption chiller. The equations are presented below and the different temperatures can be seen in Figure 61.

$$R = \frac{T_{cond} - T_{boi}}{T_{gen} - T_{cond}}$$

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[134] Johansson E., Interview, 2007
[135] Mechanical Engineering at Michigan Tech, 2000

$$COP_n = \frac{T_{boi}}{T_{gen}} \cdot \frac{1}{R}$$

The cooler needs to work with a temperature of 10°C (T_L) and the back cooling temperature will follow the outdoor temperature with the addition of the efficiency of the heat exchangers (T_{cond}). The temperature difference between the stream in and the stream out from the exchangers is set to 5°C. [136] This gives the following input temperatures.

$$\vec{T}_{cond} = \vec{T}_{out} + \Delta T_{cond} = 298.7 + 5 = 303.7 \text{ K}$$
$$\vec{T}_{gen} = T_{\tan k} + \Delta T_{gen} = 363 - 5 = 358 \text{ K}$$
$$\vec{T}_{boi} = \vec{T}_L = 283 \text{ K}$$

This leads to a mean Carnot cooling factor of:

$$R = \frac{T_{cond} - T_{boi}}{T_{gen} - T_{cond}} = \frac{303.7 - 283}{358 - 303.7} = 0.38$$

$$COP_n = \frac{T_{boi}}{T_{gen}} \cdot \frac{1}{R} = \frac{283}{358} \cdot \frac{1}{0.38} = 2.0$$

For calculation of the cooling factor the same input temperatures are compared with the designers diagram below. The theoretical values were presented for a back cooling temperature of 35 °C. To get a precise value the heating temperature was set to 100°C

[136] Wimmerstedt R., Studentlitteratur, 2001

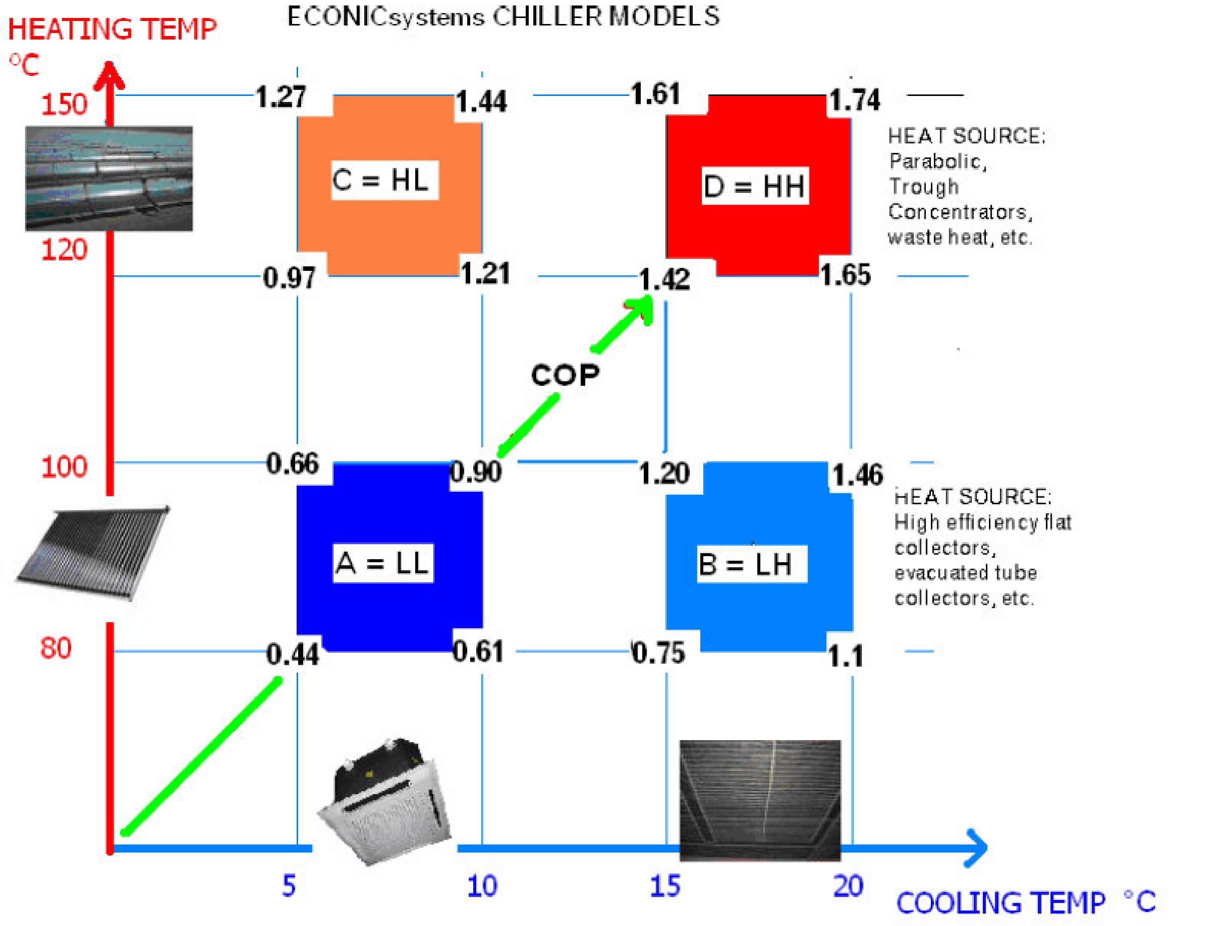

Figure 62; Absorption Chiller COP diagram depending on input heating and output cooling temperatures.[137]

This gives:

$COP_{diagram} = 0.9$

The calculated Carnot cooling factor when the outdoor temperature is 34.3 °C (which is the annual highest outdoor temperature in Guayaquil) is 1.42.

The COP changes linearly for the back cooling/outdoor temperature, according to ECONICsystems. This means that the Carnot cooling factor can be multiplied with a constant to receive the real cooling factor for the changing temperatures. This constant (K_C) can be calculated to:

$$K_C = \frac{COP_{diagram}}{COP_n}$$

$$K_C = 0.63$$

This constant is multiplied with every COP.

$COP = K_C \cdot COP_n$

The mean COP is calculated to:

$COP = 0.63 \cdot 2.0 = 1.3$

[137] Technology update from Econicsystems' November 2006

From the cooling factor and the solar system effect, the cooling effect can be calculated

$P_{cooling} = COP \cdot P_{solarsystem} = 1.3 \cdot 464 = \underline{603.2\ \text{W}}$

The system has some requirements that need to be fulfilled to make the system work.

- ~ The system should be designed to keep a mean temperature in the tank of 90°C.
- ~ The absorption chiller needs a temperature in the tank between 80 -100°C to work.
- ~ No power will be removed from the solar system when the absorption chiller is not working (T is less than 80°C).
- ~ The temperature in the tank can't sink under the outdoor temperature or above 100°C.

These are all requirement regarding the tank and these are things that need to be taken under consideration because the system characteristics will change thanks to this. The tank temperature will be affected by the temperature of the tank the hour before. To solve this, the tank temperature was calculated and programmed to follow the requirements.

The temperature in the tank was calculated with this equation.

$$\vec{T}_{\tan k} = \frac{\vec{Q}_{sun}}{\bar{c}_{p,T \tan k} \cdot m_{curcuit}} + \vec{T}_{\tan k, hourbefore} - \frac{\vec{Q}_{abssystem}}{\bar{c}_{p,T \tan k} \cdot m_{curcuit}} - \frac{\vec{Q}_{losses}}{\bar{c}_{p,T \tan k} \cdot m_{curcuit}}$$

The solar panel effect during the hour (Q_{sun}) will heat the water in the tank and the circuit and give raise to a temperature in the tank. The counter effect is the energy used by the absorption chiller and the heat losses.

$$\vec{Q}_{sun} = \vec{P}_{solarpanel} \cdot \vec{t}_n$$
$$\vec{Q}_{abs.system} = \vec{P}_{solarsystem} \cdot \vec{t}_n$$
$$\vec{Q}_{losses} = \vec{P}_{sphl} \cdot \vec{t}_n + \vec{P}_{\tan klosses} \cdot \vec{t}_n$$

The weight of the tank is.
$M_{circuit} = \rho_{water} \cdot V_{curcuit} = 1000 \cdot 0.21 = 210$ kg

The temperature is the mean temperature in the solar panel which is the $T_{solarpanel}$. The temperature is around 360 K which gives a c_p= 1.17 Wh/kg,K.[138]

The temperature in the tank is programmed in Excel to follow the requirements. The hours that the temperature is less than 80°C is counted and the output to the absorption chiller is stopped during these hours.

<u>Specific values for the vacuum solar panel.</u>
The values are a mix of values from the solar panel in Ecuador (Techno sol), a similar solar panel in Sweden and approximated values. The source of the values is given after every value.

[138] Wester L., 2003

β= 30°	Tilt of solar panel	(TechnoSol)
γ= 0°	Direction of panel	(Solar panel facing south)
K_e= 0.63 W/m^2,K	Panel efficiency	(Solarit AB)
$\eta_{transparancy}$= 0.98	Transparency	(Solarit AB)
A_{tank}= 1.89 m^2	Area tank	(calculated from the total width of vacuum tubes)
$A_{vacuumpipe}$= 2.37 m^2	Vacuum pipe area	(Technosol)
A_{panel}= 3.9 m^2	Area panel	(Technosol)
$V_{circuit}$= 0.21 m^3	Volume circuit	(TechnoSol)
V_{tank}= 0.19 m^3	Volume tank	(TechnoSol)
ρ_{water}= 1000 kg/m^3	Density water	

I_d= Climate file for Guayaquil. (W/m^2) Diffuse radiation
I_h= Climate file for Guayaquil. (W/m^2) Global radiation
α_s= Climate file for Guayaquil. (Degrees) Solar height
γ_s= Climate file for Guayaquil. (Degrees) Solar azimuth
T_{sunout}= Constant due to the difference in water speed and circulation with varying solar intensity. Set to 100°C or 373 K. Temperature out from solar panel.
T_{return} = Has the same temperature as T_{sunin} Temperature in to solar panel.
T_{abs}= Temperature in absorber.

h_H= 50 W/m^2,K	Local convection co-efficient on the hot side(inside tank)
h_L= 25 W/m^2,K	Local convection co-efficient on the cold side(outside tank)
λ= 0.038 W/m,K	Conduction depending on the material.
dx= 0.055 m	Thickness of insulation.

Calculation of the parameters I_g, I_b and I_d.

Parameters and equations:

Solar radiation:
I_{tot}= Total solar radiation towards a surface.
I_h= Horizontal total solar radiation
I_b= Solar radiation from beam
I_d= Solar radiation diffuse
I_g= Solar radiation ground
$I_{b,n}$= Solar radiation beam to the incidence angle
θ= Solar incidence of tilt angle
θ_z= Solar incidence orthogonally to the ground
α_s= Solar height
β= Tilt of the solar panel
γ= Angle of solar panel from the south
γ_s= Solar azimuth
$I_{b,h}$= Horizontal solar beam
$I_{d,h}$= Horizontal diffuse solar radiation
ρ= Ground reflection

Direct radiation:

$$\vec{I}_b = \vec{I}_{b,n} * \cos(\theta)$$

$$\theta = \arccos(\cos(\alpha_s) * \sin(\beta) * \cos(\gamma_s - \gamma) + \sin(\alpha_s) * \cos(\beta))$$

$$\vec{I}_{b,h} = \vec{I}_{b,n} * \cos(\theta_z)$$

$$\theta_z = 90 - \alpha_s$$

$$\vec{I}_{b,h} = \vec{I}_h - \vec{I}_{d,h}$$

Diffuse radiation:

$$\vec{I}_d = \frac{\vec{I}_{d,h} * (1 + \cos(\beta))}{2}$$

Radiation reflected from the ground:

$$\vec{I}_g = \frac{\rho * \vec{I}_h * (1 - \cos(\beta))}{2}$$

Total radiation is the sum of the three added radiations[139]:

$$\vec{I}_{tot} = \vec{I}_g + \vec{I}_b + \vec{I}_d$$

The possible energy collected by the solar system can be calculated depending on location, tilting angle, angle toward the south and the efficiency for the solar panel.
Since these values generate a vector, only the mean values for the whole year will be accounted for.

I_g= 2.2 W/m^2
I_d= 98 W/m^2
I_b= 52.3 W/m^2

I_{tot}= 152.5 W/m^2

Calculation of solar panel heat loss.

The efficiency of the solar panel is calculated with "Karlssons equation":

η= Absorbed sun energy of the totally received. (%)
η_0= Part of the solar radiation that reach the collector. (%)
K_0= K_1= Specific values for the heat loss for the solar panel
k_e= Calculated heat loss factor for the system
$A_{vacuumpipes}$= Area of the vacuum pipes. (m^2)
P_{sphl}= Solar panel heat loss (W)
T_{sunout}= Temperature after heated in the solar panel. (K)
T_{out}= Surrounding temperature, here outdoor temperature (K)
$T_{solarpanel}$= Mean temperature in the solar panel. (K)

$$T_{solarpanel} = \frac{T_{sunout} + T_{sunin}}{2}$$

[139] Karlsson B., Course in Solar Energy, Given by LTH autumn 2004

Karlssons equation: [140]

$$\eta = \eta_0 - \frac{k_0}{(I_{tot} \times (T_{solarpanel} - T_{out}))} - \frac{k_1}{(I_{tot} \times (T_{solarpanel} - T_{out})^2)}$$

$K_e = K_0 + K_1 \cdot (T_{solarpanel} - T_{out})$

Can also be written

$$\vec{P}_{sphl} = K_e \cdot A_{vacuumpipes} \cdot (T_{solarpanel} - T_{out})$$

The heat loss from the solar panel is depending on the mean temperature in the solar panel. The temperature out from the panel is set to 100°C and the other is assumed to be the returning temperature from the absorption chiller. Three heat exchangers need to be passed to calculate this temperature. The process can be followed in Figure 61.

The return temperature is the temperature that returns to the tank and to the solar panel. The water from the tank passes through the generator and exchange heat with the colder stream T_{abs}. The generator is assumed to be a counter flow heat exchanger which makes the temperature change like in Figure 63. The difference between in and out temperature in the heat exchangers are set to 5°C.

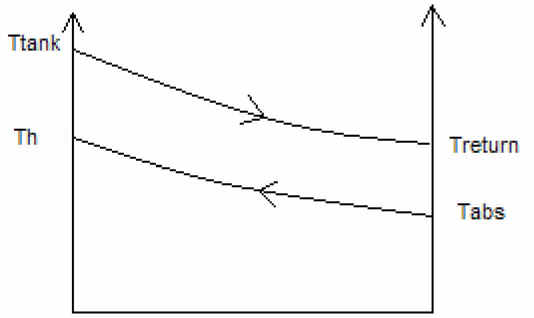

Figure 63; Show how the temperature changes through the heat exchanger.

$$\Rightarrow \vec{T}_{return} = \vec{T}_{abs} + 5^\circ C$$

T_{abs} pass through a heat exchanger as well. This is the heat exchanger between the generator and the absorber. The two streams in this exchanger do not have an equal mass flow and the flow with temperature T_h is assumed to be half of the other flow with temperature T_{abs}. As can be seen in Figure 61, there are two streams out from the generator which makes the hot stream smaller and will not be able to increase the temperature in the colder stream as much as in the other heat exchangers. The temperature T_{abs} is assumed to be:

$$T_{abs} = \frac{T_h/2 + T_{out} + 5}{2} = \frac{T_{\tan k} + T_{out} + 2{,}5}{2}$$

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[140] Andrén L., 2001

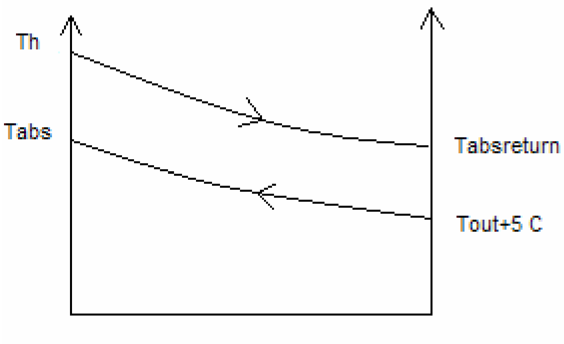

Figure 64, Temperatures in the heat exchanger between the generator and absorber.

Mean return temperature.
T_{return}= 332 K

Mean temperature in the solar panel. The T_{sunin} is equalized to the T_{return}.

$$\vec{T}_{solarpanel} = \frac{T_{sunout} + \vec{T}_{retur}}{2} = \frac{373 + \vec{T}_{retur}}{2}$$

$T_{solarpanel}$= 353 K

Heat loss from the solar panel.

$$\vec{P}_{sphl} = K_e \cdot A_{vacuumpipe} \cdot \left(\vec{T}_{solarpanel} - \vec{T}_{out}\right) = 0.63 \cdot 2.37 \cdot \left(\vec{T}_{solarpanel} - \vec{T}_{out}\right)$$

The loss from the solar panel generates a list of values and mean solar panel heat loss for every hour of the year is:

P_{sphl}= 80 W

Calculations of tank heat losses

$P_{losstank}$= Heat loss tank. (W)
A_{tank}= Area of the tank. (m^2)
l= Approximated length of tank. (m)
r= Tank radius. (m)
V_{tank}= Volume of the tank. (m^3)
k= Heat flow co-efficient. (W/m^2,K)
h_H= Local convection co-efficient on the hot side(inside tank) (W/m^2,K)
h_L= Local convection co-efficient on the cold side(outside tank) (W/m^2,K)
λ= Conduction depending on the material. (W/m,K)
dx= Thickness of material. (m)
T_{tank}= The temperature out from the tank. (K)

$$r = \sqrt{\frac{V_{\tan k}}{l \cdot \pi}} = \sqrt{\frac{0.19}{1.89 \cdot \pi}}$$

r = 0.179 m
$A_{tank} = 2 \cdot \pi \cdot r \cdot l = 2 \cdot \pi \cdot 0.179 \cdot 1.89 = 2.12$ m

$$\frac{1}{k}=\frac{1}{h_H}+\frac{dx}{\lambda}+\frac{1}{h_L}$$

$$\frac{1}{k}=\frac{1}{50}+\frac{0.055}{0.038}+\frac{1}{25}=1.507$$

$$\Rightarrow k=0.66W/m^2K$$

$P_{losstank}=k\cdot A_{\tan k}\cdot(T_{\tan k}-T_{out})=0.66\cdot 2.12\cdot(T_{\tan k}-T_{out})$[141]

The loss from the tank generates a list of values.

Effect and temperature from solar system and cooling effect

$P_{solarpanel}$= Solar panel effect (W)
$P_{solarsystem}$= Solar system effect (W)
A_{panel}= Area of solar panel.
$V_{circuit}$=Volume of the solar panel circuit.
$M_{circuit}$= Weight of the fluid in the tank.
ρ= Density of the fluid
$T_{out}=\vec{T}_{File}$
T_{gen}= Temperature in generator.
T_{boi}= Temperature in boiler.
T_{con}= Temperature in condenser
ΔT_{gen}= Temperature difference in heat exchanger in the generator.
ΔT_{abs}= Temperature difference in heat exchanger in the absorber.
ΔT_{boi}= Temperature difference in heat exchanger in the boiler.
ΔT_{con}= Temperature difference in heat exchanger in the condenser.
T_{sunin}= Temperature in to the solar panel.
T_{sunout}= Temperature out from the solar panel.
T_{return}= The temperature after the generator. (K)
ΔT_{gen}= Temperature difference in heat exchanger in the generator.
$\vec{t}$ = Every hour of the year.
c_p= Specific heat value for water at $T_{solarpanel}$ in (Wh/kg,K) also dependent on the pressure.
Q_{sun}= The energy received by the solar panel. (Wh)
$Q_{abssystem}$= The energy used by the absorption chiller. (Wh)
$\overrightarrow{COP}_n$ = Carnot cooling factor for the varying outdoor temperature.
R= Reduction factor.

$$\vec{P}_{solarsystem}=P_{solarpanel}-P_{SPHL}-P_{loss\tan k}$$

The calculation generates a list of values.

Calculation of the cooling factor for absorption chiller.

T_{gen}= 363 K - ΔT_{gen}
T_{boi}= 283 K
T_{con}= Climate file + ΔT_{con}
ΔT_{gen}= 5 °C

[141] Alvarez H., 2003

$\Delta T_{con} = 5\ °C$

$$R = \frac{T_{cond} - T_{boi}}{T_{gen} - T_{cond}}$$

$$COP_n = \frac{T_{boi}}{T_{gen}} \cdot \frac{1}{R}$$

$$\vec{T}_{cond} = \vec{T}_{out} + \Delta T_{cond}$$

$$\vec{T}_{gen} = T_{\tan k} - \Delta T_{gen}$$

$$\vec{R} = \frac{T_{cond} - T_{boi}}{T_{gen} - T_{cond}} = \frac{\vec{T}_{out} + 5 - 283}{\vec{T}_{\tan k} - 5 - \vec{T}_{out} - 5}$$

$$COP_n = \frac{T_{boi}}{T_{gen}} \cdot \frac{1}{R} = \frac{283}{373} \cdot \frac{1}{\vec{R}}$$

The lists of outdoor temperatures and the calculated temperatures in the tank are used in this equation. To generate a list of Carnot cooling factors. The Carnot cooling factors are compared to the real test values as above. The list of cooling factors and effects out from the system are multiplied to receive a list cooling effect.

$$\vec{P}_{cooling} = \overrightarrow{COP} \cdot \vec{P}_{solarsystem}$$

Calculation of temperature in tank.

$$\vec{T}_{\tan k} = \frac{\vec{Q}_{sun}}{\bar{c}_{p,T\tan k} \cdot m_{curcuit}} + \vec{T}_{\tan k,daybefore} - \frac{\vec{Q}_{abssystem}}{\bar{c}_{p,T\tan k} \cdot m_{curcuit}} - \frac{\vec{Q}_{losses}}{\bar{c}_{p,T\tan k} \cdot m_{curcuit}}$$

$$\vec{Q}_{sun} = \vec{P}_{solarpanel} \cdot \vec{t}_n$$

$$\vec{Q}_{abs.system} = \vec{P}_{solarsystem} \cdot \vec{t}_n$$

$$\vec{Q}_{losses} = \vec{P}_{sphl} \cdot \vec{t}_n + \vec{P}_{\tan klosses} \cdot \vec{t}_n$$

Example:

$\vec{Q}_{sun} = \vec{P}_{solarpanel} \cdot \vec{t}_n = 1000$ Wh

$\vec{Q}_{abs.system} = \vec{P}_{solarsystem} \cdot \vec{t}_n = 200$ Wh

$\vec{Q}_{losses} = \vec{P}_{sphl} \cdot \vec{t}_n + \vec{P}_{\tan klosses} \cdot \vec{t}_n = 30 + 70 = 100$ Wh

$T_{tank,hour\ before} = 350$ K

$$\vec{T}_{\tan k} = \frac{1000}{1.17 \cdot 210} + 350 - \frac{200}{1.17 \cdot 210} - \frac{100}{1.17 \cdot 210} = 352.8 \text{ K}$$

Appendix 11; Calculation of Mean Carbon and Ash Concentration in the Samples of Organic Solid Waste from Guasmo

In this appendix the mean carbon concentration or VS concentration as it is also called and the mean ash concentration will be calculated. The raw data used is the visually approximated mass composition of the collected samples of organic solid waste from Guasmo. A nutrient table is used together with the water content to calculate the carbon and ash concentration. Only the components in the samples with the 30 largest mass percentages are used. The following equations were used:

$$\overline{C}_{ash} = \frac{\sum_{k=1}^{n=18} C_{ash}}{n_{C_{ask}}} = \frac{\sum_{k=1}^{n=18} 1 - C_{H_2O} - C_{fat} - C_{proteines} - C_{carbohydrates} - C_{fibers}}{n_{C_{ask}}}$$

$$\overline{C}_{C} = \frac{\sum_{k=1}^{n=49} C_{C}}{n_{samples}} = \frac{\sum_{k=1}^{n=49} 1 - c_{moisture} - \overline{C}_{ask}}{n_{samples}}$$

C_{ash} = Ash concentration in component n

$\overline{C}_{ash}$ = Mean ash concentration

$\overline{C}_{C}$ = Mean carbon concentration in samples of organic solid waste from Guasmo

C_{C} = Carbon concentration in sample n

C_{H_2O} = Mass concentration of waster in component n

C_{fat} = Mass concentration of fat in component n

$C_{proteines}$ = Mass concentration of proteins in component n

$C_{carbohydrates}$ = Mass concentration of carbohydrates in component n

C_{fibers} = Mass concentration of fibres in component n

$n_{samples}$ = Number of samples

$c_{moisture}$ = Mass concentration of water in sample n

$n_{C_{ask}}$ = Number of components

A nutrient table was constructed with 30 of the components in the organic solid waste, this can be seen beneath. The contents are given in percentage of a sample of 100g.

Table 14. Nutrient Table.

	C_{fat}	$C_{proteines}$	$C_{carbohydrates}$	C_{fibers}	C_{H_2O}	C_{ash}

Banana[142]	0.5	1	21.8	1.7	74	0.01
Rice[142]	0.4	2.6	27.19	0.61	68.2	-
Cantaloupe	0.3	0.9	7.4	1	90	0.004
Lime[142]	0.2	0.7	10	0.5	88	0.006
Potatoes[142]	0.1	1.81	16.14	1.4	-	-
Coconut (flakes)[142]	-	-	-	-	-	-
Pineapple[142]	0.4	0.4	11.2	1.2	86	0.008
Water melon[142]	0.43	0.62	7.18		91.5	0.0026*
Egg Shells	-	-	-	-	-	-
Carrot[142]	0.24	0.6	8.69	2.4	87.5	0.0057
Bread[143]	6.65	8.4	45.03	5	-	0.00154*
Leafs (spinach)[142]	0.5	1.9	0.6	1.3	94	0.017
Cucumber[142]	0.05	0.81	2.12	0.73	95.9	0.0039
Pepper[142]	0.06	0.81	3.31	2	93.4	0.0042
Orange[142]	0.1	0.8	10.3	1.9	86	0.009
Passion Fruit[144]	0.7	2.2	23.38		72.93	0.008*
Papaya[145]	0.14	0.61	9.81	-	88.8	0.006102*
Avocado[142]	15.3	2	4.1	3.3	74	0.013
Broccoli[142]	0.27	3.5	3.12	3.1	-	-
Onion (yellow)[142]	0.1	1.2	6	1.2	91	0.005
Corn[142]	1.61	3.88	22.06	2.88	68.8	0.0077
Beans[142]	0.6	5.6	7.5	4.2	-	-
Tomato[142]	0.13	0.88	3.72	1.4	93.4	0.0047
Beat root[146]	0.1	1	9.9	-	-	-
Apple[142]	0.05	0.27	12.43	1.8	-	-
Madura (plataine)[142]	0.4	1.3	30.3	1.7	65	0.013
Tree tomato	-	-	-	-	-	-
Chicken[142]	1.3	21.5	-	-	-	-
Coli Flour[142]	0.17	1.56	3.85	2.42	-	-
Pumpkin[142]	0.1	1	4.8	1.7	-	-
Peas[142]	0.54	11.56	24.75	5.35	-	-
Mean						0.007191
Standard deviation						0.004024

* = The ash concentration is directly taken from the source.

For the compounds that have ash concentrations but no fibre concentrations the fibres are included in the hydrocarbon concentrations.

$\overline{C}_{ash} = 0,007191 \approx \mathbf{0,72\ \%}$

$c_{moisture}$	C_C
0.805	0.188
0.834	0.159
0.735	0.258
0.71	0.282
0.652	0.341
0.811	0.182

142 Recepthjälpen, 2006
143 Swedish National Food Administration, version 04.1.1
144 USDA Nutrient Database for Standard Reference, Release 14 (July 2001)
145 About Inc, a part of the New York Times Company, 2006
146 Swedish National Health Institute, Fineli, 2006

0.782	0.21
0.851	0.141
0.702	0.29
0.852	0.141
0.807	0.186
0.846	0.147
0.7	0.293
0.848	0.145
0.736	0.257
0.747	0.246
0.795	0.198
0.801	0.192
0.699	0.294
0.872	0.121
0.856	0.137
0.666	0.327
0.859	0.133
0.78	0.213
0.766	0.227
0.849	0.144
0.687	0.305
0.884	0.109
0.787	0.206
0.775	0.218
0.698	0.295
0.725	0.268
0.688	0.305
0.709	0.284
0.597	0.396
0.743	0.25
0.711	0.282
0.673	0.32
0.623	0.37
0.713	0.28
0.786	0.207
0.84	0.153
0.845	0.148
0.833	0.16
0.718	0.275
0.841	0.151
0.661	0.332
0.705	0.288
0.776	0.217
Mean 0.763	0.23
Standard deviation0.073	0.073

$\overline{C}_C = 0.2292836 \approx \mathbf{23\ \%}$

Appendix 12: Calculations of Mean Moisture Concentration in Organic Solid Waste from Guasmo

In this appendix we will calculate the mean moisture concentration. The raw material used is the data collected from the performed investigation of organic solid waste in Guasmo. From all the large samples of organic waste a small representative sample was taken and brought back to the university to calculate the value of the mean moisture concentration. To calculate the mean moisture concentration the following expression was used:

$$\overline{C}_{moisture} = \frac{\sum_{k=1}^{n=49} c_{moisture}}{n_{samples}} = \frac{\sum_{k=1}^{n=49} \frac{m_{sample} - m_{drysample}}{m_{sample}}}{n_{samples}}$$

$\overline{C}_{moisture}$ = Mean moisture concentration in organic solid waste from Guasmo

$c_{moisture}$ = Moisture concentration in sample n

$n_{samples}$ = Number of samples of organic solid waste from Guasmo

m_{sample} = Mass of sample n

$m_{drysample}$ = Mass of sample n after drying it for 24 h in 105 °C

$n_{samples} = 49$

In the table below the raw data and the calculated $c_{moisture}$ can be studied.

		m_{sample}	$m_{drysample}$	$c_{moisture}$
Day 1	house 1	65.5	12.8	0.805
	house 2	89.9	14.9	0.834
	house 3	66.3	17.6	0.735
	house 4	74.6	21.6	0.71
	house 5	48.6	16.9	0.652
	house 6	100	18.9	0.811
	house 7	-	-	-
	house 8	70.8	15.4	0.782
	house 9	105	15.6	0.851
	house 10	103.5	30.8	0.702
Day 2	house 1	129.7	19.2	0.852
	house 2	180.4	34.8	0.807
	house 3	173.4	26.7	0.846
	house 4	178.1	53.5	0.7
	house 5	98.4	15	0.848
	house 6	133	35.1	0.736
	house 7	151	38.2	0.747
	house 8	110	22.6	0.795
	house 9	201.1	40.1	0.801
	house 10	132.2	39.8	0.699
Day 3	house 1	55.5	7.1	0.872
	house 2	179.3	25.9	0.856
	house 3	119.1	39.8	0.666

	house 4	83.9	11.8	0.859
	house 5	75.4	16.6	0.78
	house 6	175.2	41	0.766
	house 7	142.3	21.5	0.849
	house 8	146.5	45.8	0.687
	house 9	126.7	14.7	0.884
	house 10	124.6	26.6	0.787
Day 4	house 1	70.7	15.9	0.775
	house 2	84.1	25.4	0.698
	house 3	113	31.1	0.725
	house 4	51.2	16	0.688
	house 5	109	31.7	0.709
	house 6	202.5	81.7	0.597
	house 7	131.1	33.7	0.743
	house 8	118.9	34.4	0.711
	house 9	150.2	49.1	0.673
	house 10	86.1	32.5	0.623
Day 5	house 1	127.1	36.5	0.713
	house 2	106.9	22.9	0.786
	house 3	99.4	15.9	0.84
	house 4	69.6	10.8	0.845
	house 5	98.8	16.5	0.833
	house 6	189.1	53.3	0.718
	house 7	137.4	21.8	0.841
	house 8	105.5	35.8	0.661
	house 9	201.6	59.5	0.705
	house 10	105.3	23.6	0.776
mean				0.763
standard deviation				0.073

$\overline{C}_{moisture} \approx \mathbf{0.76 = 76\ \%}$

Appendix 13; House Specifications

Table 15. Specifications for the Base Case Standard House.

Building Element	Thickness (mm)	Material	Conductivity W/m,K	Specific Heat Wh/kg,K	Density kg/m^3	Emittance	Absorptance
Walls	100	Hollow Blocks	0.91	0.25	1200	87 %	70 %
Roof	1	Galvanized Steel	50	0.13	7800	30 %	50 %
Floor	100	Concrete	1.7	0.24	2300	87 %	70 %

Windows;

Single clear glass with a U-value of 5.88 W/m2, K, a reflection of 7 % and a transmittance of 83 %

Appendix 14; Calculation with Regulation for the Absorption Chiller.

The mean effect that can be taken out from the solar system is calculated in Appendix 10.

$\overline{P}_{solarsystem} = 464$ W

The effect is to be concentrated on only 8 hours daily instead of 24 and at the same and adapted to the yearly variations. The mean solar radiation divided in to April 1st – September 31st and October 1st – March 31st reveals that the solar radiation is 30 % lower during the colder period April 1st – September 31st. This can be seen in Table 16

Table 16; Mean Solar Effect that hits the Solar Panel divided in Two Periods

Period	Mean Solar Effect that hits the Solar Panel
April 1st – September 31st	685 W
October 1st - March 31st	479 W

This gives that the mean effect out from the solar system would be:

April 1st – September 31st $\overline{P}_{solarsystem,summer} = 383.6$ W

October 1st - March 31st $\overline{P}_{solarsystem,winter} = 548$ W

The effect concentrated on 8 hours between 11 am-7 pm every day can be calculated to:

April 1st – September 31st

$$P_{solarsystem,summer} = \frac{\overline{P}_{solarsystem,summer} \cdot 4380h/year}{8h/day \cdot {}^{365}\!/_{2}\, days} = \frac{383.6 \cdot 4380}{8 \cdot {}^{365}\!/_{2}} = 1150.8 \text{ W}$$

October 1st - March 31st

$$P_{solarsystem,winter} = \frac{\overline{P}_{solarsystem,winter} \cdot 4380h/year}{8h/day \cdot {}^{365}\!/_{2}\, days} = \frac{548 \cdot 4380}{8 \cdot {}^{365}\!/_{2}} = 1644 \text{ W}$$

The mean COP for the whole year is calculated to 1.3 in Appendix 10. The outdoor temperature during the daytime is higher and would lead to a lower COP. The outdoor temperature for the period April 1st – September 31st is lower but a lower temperature in the tank means that the COP for the two periods can be assumed the same. The COP is assumed to be 1.25.

This leads to a cooling effect for the regulated periods of:

April 1st – September 31st

$$P_{cooling,summer} = COP \cdot P_{solarsystem,summer} = 1.25 \cdot 1150.8 = 1438.5 \text{ W}$$

October 1st - March 31st

$$P_{cooling,winter} = COP \cdot P_{solarsystem,winter} = 1.25 \cdot 1644 = 2055 \text{ W}$$

The absorption cooler can only supply the house with 2000 W which will be the maximal effect.

Appendix 15; Economical Calculations for a Traditional Air-conditioner and Absorption Chiller

The running cost for the traditional air conditioning device is higher than the investment cost while it is the opposite for the absorption chiller. The running cost for the air-conditioner is highly depending on the price for the electricity and COP for the process. Both of the processes are assumed to last for 10 years.

The electricity price is calculated in Appendix 6 to be $ 0.096/kWh and the COP is assumed to be 3.[147] The investment cost for the device was investigated to be $ 300.

The Air conditioning device will be run with the same effect and time as the absorption chiller. The effect is set to 2000 W from October 1st - March 31st and 1400 W from April 1st – September 31st for 8 hours daily.

$$Cost_{cooling,traditional} = price_{electricity} \cdot t_{year} \cdot t_{working} \cdot \left(\frac{P_{cooling,winter} + P_{cooling,sumer}}{2 \cdot COP} \right) + G_{traditional,AC}$$

$Price_{electricity}$ = $ 0.096/kWh Price for electricity (Appendix 6)

t_{year} = 2920 hours, Hours working during one year (Appendix 6)

$P_{cooling,summer}$ = 1.4 kW Cooling April 1st – September 31st (Appendix 14)

$P_{cooling,winter}$ = 2 kW Cooling October 1st - March 31st (Appendix 14)

$G_{traditional,AC}$ = $ 300 Investment cost

$t_{working}$ = 10 years, Years working

COP = 3 Co-efficiency for the cooler

$$Cost_{cooling,traditional} = price_{electricity} \cdot t_{year} \cdot t_{working} \cdot \left(\frac{P_{cooling,winter} + P_{cooling,sumer}}{2 \cdot COP} \right) + G_{traditional,AC}$$

$$Cost_{cooling,traditional} = 0.096 \cdot 2920 \cdot 10 \cdot \left(\frac{2+1.4}{2 \cdot 3} \right) + 300 = \$\ 1888$$

Total cost for the absorption chiller

The investment cost for the absorption chiller is $ 2500[148] and the solar panel has price of $ 1000.[149] The pump is assumed to have an effect of 150 W and run during the time that the system is cooling.[148]

$$Cost_{cooling,abs} = price_{electricity} \cdot t_{year} \cdot t_{working} \cdot P_{pump} + G_{abs,AC}$$

$Price_{electricity}$ = $ 0.096/kWh Price for electricity

[147] Energy Smart Homes, 2006
[148] Technology update from Econicsystems, November 2006
[149] TechnoSol, 2006

t_{year} = 2920 hours, Hours working during one year

P_{pump} = 0.15 kW Effect for the pump.

$G_{abs,AC}$ = $ 3500 Investment cost

$t_{working}$ = 10 years, Years working

$$Cost_{cooling,abs} = price_{electricity} \cdot t_{year} \cdot t_{working} \cdot P_{pump} + G_{abs,AC} = 0.096 \cdot 2920 \cdot 10 \cdot 0.15 + 3500 = \$3920$$