The use of solar water heaters in Mexico City

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Abstract

During the last decade, Mexico City's air quality has deteriorated dramatically. Air pollution management has become a major issue, and a number of policies and campaigns aimed at reducing the volume of harmful emissions released into the atmosphere by vehicles and large-scale industries, have been implemented.

Lighting, office equipment, cooking, refrigeration, space heating, space cooling, ventilation, and water heating are the ultimate commercial uses of energy. The goal of this study is to determine if there is a potential market for solar water heaters that could provide hot water for a number of activities in the city, reducing the amount of fossil fuels burned for this purpose, thus contributing to decrease the amount of air pollutants to the atmosphere.

The results of this research show how a number of industries, public services and commercial activities need to be provided with both water and energy in large quantities, and are therefore potential users of solar thermal technologies.

Résumé

La qualité de l'air de la Ville de Mexico s'est détériorée notablement depuis la dernière décennie. Le contrôle de la pollution est donc devenu un sujet de rélevance et plusieurs mesures ont été prises pour réduire le volume des émissions polluantes que, jour à jour, sont liberées dans l'atmosphere par des vehicules et des larges usines.

Dans le contexte résidentiel et commerciel, l'énergie s'utilise principalement pour l'illumination, la réfrigeration, la ventilation et le chauffage des spaces, ainsi que pour la cuisson et le chauffage de l'eau. L'objectif de cet étude c'est détérminer s'il y a un marché potentiel pour l'énergie solaire thermique qui pourrait procurér de l'eau chaude pour un grand nombre d'activités dans la ville, tout en réduissant la quantité de combustible fossile qu'on utilise à ce propos, lors de réduire les émissions polluantes.

Les résultats de cet étude montrent comment un nombre d'activités industrielles, des services publics, et des activités commercielles doivent être munies avec les deux, de l'eau et de l'energie en grande volume et sont donc, des utilisateurs potentiels des technologies solaires thermiques.

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Chapter 1: Introduction

A number of policies and programs introduced to improve energy efficiency and demand management were initiated as a result of the petroleum price raise during the 1970s and early 1980s. These improvement programs which were launched by many countries, particularly the oil-importing ones, included strategies for energy conservation, fuel diversification, and the use of renewable resources. Technologies employing renewable resources, such as wind, solar, geothermal, and biomass, attracted attention as their potential as substitutes for fossil fuels was being tested. Nevertheless, the strategies for use implemented by industrialised nations differed from those employed by developing countries. According to Gamba, while industrialised nations achieved significant energy savings through demand management, developing countries focused their strategies on increasing the domestic energy supply (Gamba, 3).

As an oil-exporting developing country, Mexico has yet to face the necessity for using renewable technologies to replace fossil fuels to meet its national energy requirements. However, Mexico's economy, being strongly based on petroleum exports, was seriously affected during 1998 as a consequence of the decline in petroleum prices in the international market (figure 1.1). This is not the first time that Mexicans have faced economic crises. Historically, the cost of petroleum-derived combustibles and electricity has increased monthly and so has the price of essential goods (figures 1.2 and 1.3).

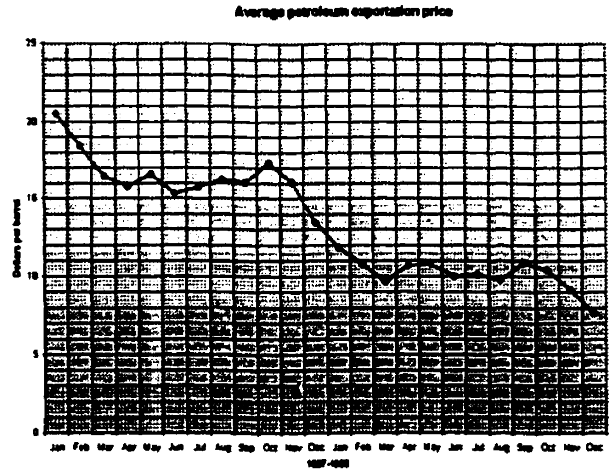

Figure 1.1 Average exportation price for Mexican petroleum.
Source: PEMEX, 1999

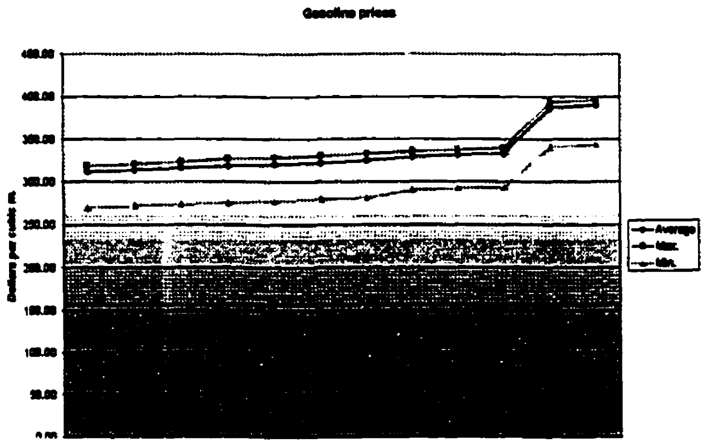

Figure 1.2 Gasoline prices in Mexico 1997-1998.
Source: CONAE, 1999.

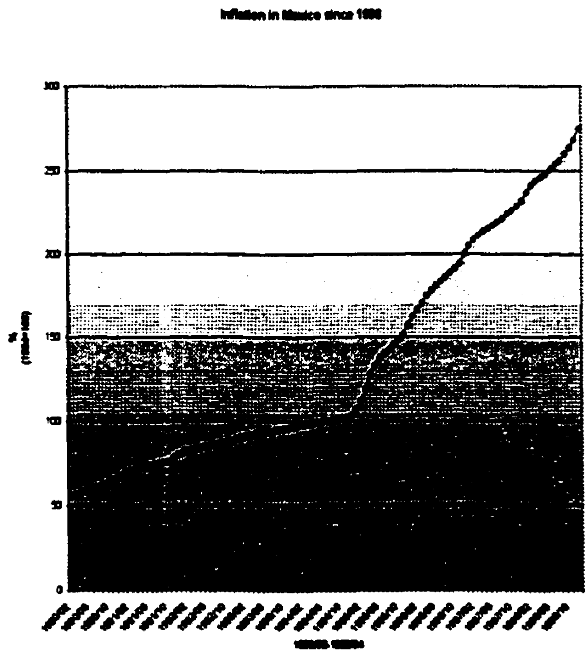

Figure 1.3 Inflation in Mexico since 1990.
Base year 1994.
Source: INEGI, 1998

This critical economic situation has, over time, been a major cause of the migration of the rural population to the cities, especially to Mexico City, and its metropolitan area, whose population is projected to grow to 26.3 million people in year 2000. Consequences of such a rapid and unplanned urbanisation process range from social tensions (violence, insecurity, and various forms of delinquency), the inability of municipalities to provide services (water, sewage, power supply), the lack of an efficient transportation network, and environmental pollution. During the last decade, Mexico City's air quality has deteriorated dramatically. Air pollution management has become a major issue, and a number of policies and campaigns aimed at reducing the volume of harmful emissions released into the atmosphere by vehicles and large-scale industries, have been implemented.

Studies made by the National Institute of Ecology in Mexico (INE), reveal that the public service sector is responsible of the 39% of the suspended hydrocarbons in the atmosphere, produced mainly from incomplete burning processes. The public service sector embraces a large variety of functions undertaken in restaurants, bakeries, laundries, tortillerías, public baths, retail outlets, and so on. Figure 1.4 shows the most important commercial activities and their percentage of the energy consumption.

Lighting, office equipment, cooking, refrigeration, space heating, space cooling, ventilation, and water heating are the ultimate commercial uses of energy. The use of hot water may not be significant for certain kinds of enterprise; however, it is vital for the operation of a number of establishments such as laundries, sport-clubs, hospitals and public baths.

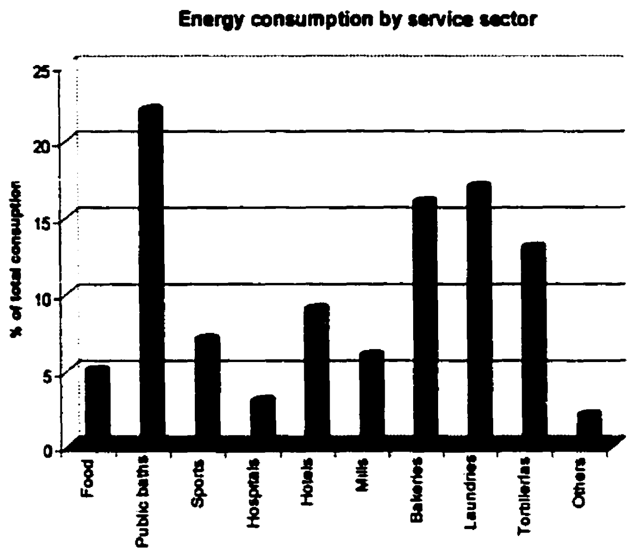

Figure 1.4 Energy consumption by service sector
Source: Environmental Software & Services, 1998

The amount of energy used to heat water varies according to the size of the company, temperature requirements, and water-heating systems, and under these circumstances, opportunities to save energy and reduce harmful emissions are substantial. Thus, this study considers the commercial and public service sectors as a potential consumers of renewable technologies for water heating. Moreover, because there are few programs in place aimed at the reduction of energy consumption in homes, this thesis will also study the feasibility of implementing solar water heaters for domestic use, on a large scale, by middle-to-high-income households in Mexico City.

1.1 Rationale for the Study

1.1.1 Energy management

Human beings need a constant source of energy in order to survive. As Bharier has observed, the demand for energy is a demand not for energy of fuel *per se*, but for the services that it can perform –for heat, light, and motive power. These services can be provided in different ways, and with different levels of efficiency, by different energy sources (Bharier, 25). Thus, to exploit and benefit from those resources, a number of technologies have been developed.

For more than a century, fossil fuels such as petroleum, gas, and coal, were the world's principal sources of energy. Origins of fossil fuels and possible locations of supplies are well known, and global reserves can be estimated using this information. However, due to the complexity of the estimation process and the variety of assumptions employed for calculating, it is difficult to be certain of their magnitude. Estimates must take into account economic and technological aspects related to the exploitation of available resources. Knowledge of the required investment, in terms of energy, is critical to ensure that the energy expended on exploitation does not exceed the amount of energy ultimately provided by the resource. In this regard, government plays a significant role in energy management. In Bharier's opinion, the management of energy demand implies direct intervention in the energy market by the government. But whether the government carries out all the measures itself or simply provides the incentives for these measures will depend on the situation in individual countries. By and large there will always be some need for direct government action, if only to increase the efficiency of energy use in the public sector:

> In those industrialised nations where the right incentives have been given, energy demand management has been handled largely by the private sector. Indeed, it has turned out to be a profitable business for the producers of insulation material, heat pumps, and small, fuel-efficient cars. Energy consumers have generally estimated that the benefits of increased energy efficiency or fuel switching outweigh the costs, and they have invested in the appropriate new equipment. In many developing countries, however, the benefits of increasing the efficiency of energy use are often not as obvious to householders or industrialists. One reason is that the general level of energy use is lower than in the industrialised countries. A second is that the turnover of machinery, equipment, and appliances is generally slower. A third reason is that the energy-users simply cannot afford new equipment or appliances. And a fourth reason is that tradition plays a much more important role ... Nevertheless, energy demand management, including both, greater efficiency of energy use, and fuel switching, is possible in the developing countries. (Bharier, 25-6).

According to the National Committee for Energy Saving (Comisión Nacional para el Ahorro de Energía, CONAE), there are three major energy-using sectors in Mexico:

industry and mining; transport; and residential, commercial and public (figure 1.5). Gamba considers that it may be most beneficial to focus initially on measures for energy demand management on the industrial sector, where improvements can be made with relative speed through a combination of policy, technical, institutional, and financial measures.

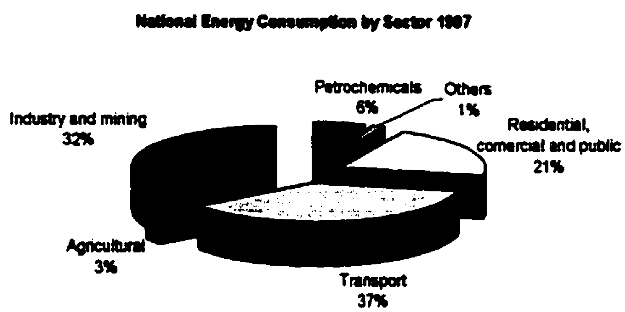

Figure 1.5
Source: CONAE. 1999

1.1.2 Environmental impact

The industrialisation process associated with the oil business has prompted a number of changes in energy consumption patterns. This is the result of the increase in association, primarily by urban dwellers, of technology —or even worse, resource waste— with comfort and wealth. As a result, technology has changed both the physical world and the way human beings interact with it. However, increasing costs and the environmental impact due to extraction, transformation and combustion of fossil fuels contribute significantly to the shift to renewable resources, such as solar and wind energy, and to the origin of new policies for the rational use of non-renewable resources.

For environmental purposes, fuels are evaluated in terms of the chemical substances they produce in combustion. Attention must be drawn to the problems of global warming and acid rain caused by high-energy consumption all around the world. Nevertheless, changing to non-pollutant renewable energies from fossil fuels is not always an affordable proposition, especially for low-income groups or small-scale businesses.

1.1.3 The case of Mexico City

The Mexico City metropolitan area (MCMA) consists of more than 4,000 square kilometres, comprising the Federal District (home of the Government) and 21 adjacent municipalities in the State of Mexico. Population growth of 5% per year from 1940 to 1980 and 2% during the first half of the 1990s resulted in nearly 17 million inhabitants in 1995, making the MCMA one of the largest cities of the world. Mexico City is the county's political, economic, industrial, and social capital, and about 20% of the national population lives there. The city provides 47% of all industry jobs, and 48% of public investment in social welfare. It also contains 30% of all the industrial plants in the country, and has about 3 million motor vehicles (Scott, 410).

According to the National Institute of Statistics, Geography and Informatics (INEGI), Mexico has an energy consumption of 1.439 tons per capita of petroleum or its equivalent. Nevertheless, this number reflects mostly an urban consumption pattern, as large human settlements are more likely to use higher amounts of fuels. Figure 1.6 shows the kind of fuels used in the MCMA per sector.

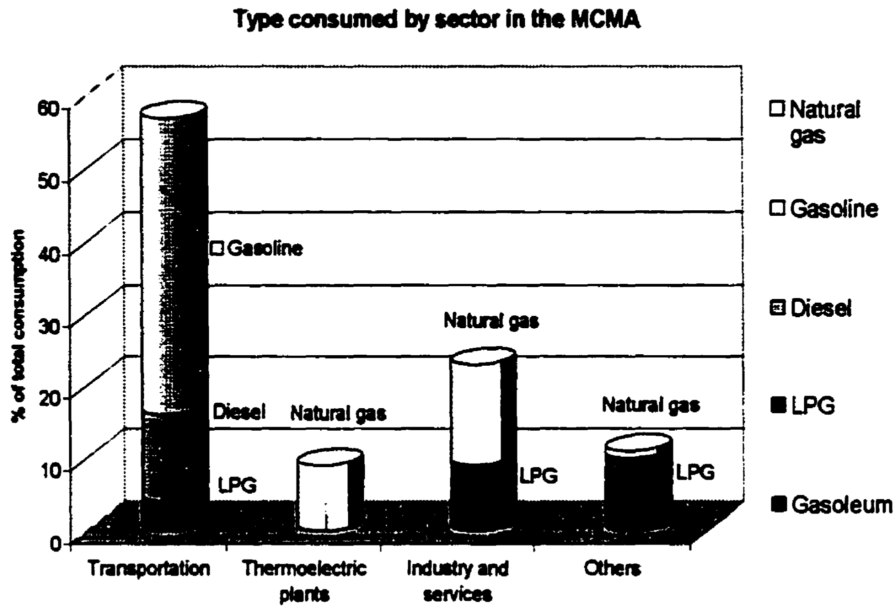

Figure 1.6 Type of fuel consumed in the MCMA
Source: Environmental Software & Services, 1998

Mexico City is located in a deep bowl valley surrounded by a ring of mountains at approximately 2,300 meters above sea level, which creates a natural isolation that contributes to frequent thermal inversions (especially in winter) and prevents the dispersion of pollutants (See figure 2.2 in chapter 2).

Ecological damage has been aggravated by inadequate measures for the protection of the local environment. A comprehensive program of action was announced in 1990, intended to rationalise urban transport, improve the environmental qualities of fuels burned, install pollution-control equipment, and regenerate natural areas. Despite all these measures, atmospheric pollution still poses a serious threat to human health. Public officials acknowledge that employment and productivity in the urban economy still takes precedence over environmental preservation. Furthermore, some industrial plants have yet to install anti-pollution devices. Because of the high cost involved, these plants be dependent on projected state credit programs that are to be implemented in future years to afford these devices (Scott, 410).

Liquefied petroleum gas (LPG) is the most popular fuel employed domestically for the heating of water in the MCMA. At first glance, this appears to be a viable option: Its performance is good (estimated thermal efficiency is about 75%), its cost is low ($3.41 pesos/Kg)[1] and the national production is sufficient to meet actual and future demand. But a second consideration of this product reveals that:

a) Performance is also related to the type and model of heater employed; old or deteriorated heaters consume more energy.

b) Initially, the cost of LPG is low because the government subsidizes it. However, once the subsidies expire, the monthly cost of LPG will increase according to the country's inflation rates and to the international cost of oil. Unfortunately, at the domestic level of consumption, salaries do not keep pace with inflation.

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[1]One American dollar = 10 pesos. Price for August 1999, including tax.

Solar Water Heaters (SWH) offer a renewable, non-polluting and low maintenance technology for supplying hot water for domestic and industrial use. However, some people may not consider it to be their best option for a variety of reasons, including those related with education about renewable technologies, or financial concerns that prohibit residents from making the initial investment.

Nevertheless, the critical situation that the city faces in terms of further environmental damage and public health must not be ignored. It is hoped that this study will contribute to the analysis of some of the hazards that challenge the future of the MCMA, and will contribute to further consideration of the adoption of energy efficient, non-polluting and safer technologies as a way to ease its present condition.

1.2 Research Question

1. Can the use of solar water heaters be increased in Mexico?
2. In which sector can solar water heaters be introduced?

    2.1 Who can afford them?

    2.2 What are the traditional methods for water heating and the consumption patterns for energy and water?

        2.2.1 For domestic use (medium-high income households)

        2.2.2 In small-medium businesses that require large amounts of hot water

3. What are the long-term benefits of using solar water heaters in Mexico City?

    3.1 Should a shift to solar energy use be for economic reasons alone?

1.3 Goals and Objectives

The goals of this study are:

- To determine if there is a potential market for SWH in the MCMA.
- To determine if there are potential savings in monthly/annual costs of energy consumption using SWH in comparison with conventional water heaters.

Objectives are:

- To discover patterns of hot water consumption
    - For medium/high income families
    - For small/medium businesses that require large amounts of hot water
- To suggest what the adverse effects are in the case of use of conventional fuels

- To suggest the amount of savings using SWH, if any
- To suggest who can afford a SWH
- To discover the positive impact on the environment, if any
- To initiate an educational process which will have an impact on a new energy conservation culture.

1.4 Methodology

This study is based on the analysis of a variety of data. The following material is examined in order to provide background information on the possibilities of implementing the solar thermal technology in the MCMA:

- *Environmental data*. Principal pollutants and sources of air pollution, effects of pollutants for human health, and environmental statistics for the MCMA
- *Water and energy data*. Water provision in the MCMA, rates for domestic and non-domestic water use, patterns of water consumption, relationship between energy and water provision.
- *Water heater systems.* Traditional water heaters for industrial, commerce, and residential use, efficiency of heaters, fuel consumption and fuel prices.
- *Case study*. Analysis of the actual requirements of hot water for a building and how a series of solar water heaters contribute to the daily supply.

1.5 Literature Review

Increasing costs and the environmental impact of extraction, transformation and combustion play a significant role in the need to renewable resources and sustainable development. The latter term has been defined by The World Commission on Environment and Development's 1987 report *Our Common Future* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Funston).

Sustainable development in a country implies a constant, and long-term economic evolution that grants better living standards (employment, education, and health services) to its inhabitants. Over the past two decades, a number of government agencies have begun to include environmental issues in their agendas and to dedicate financial resources to research on renewable energy resources. Similar efforts are being made by international agencies, universities and private institutes in which scholars, professionals, and technicians do applied research in order to develop new technologies.

The U.S. Department of Energy (DOE) maintains a World Wide Web site called the Energy Efficiency and Renewable Energy Network (EREN), which provides access to information about renewable energy and energy efficient technologies throughout the world. DOE services include information on state solar energy legislation, regulations, and listings of state and private energy organizations. State centers can provide more specific information on available state incentives, regulations, and in-state programs.

Information on seminars and conferences is also available from these centers. Many of them can also provide a referral service for builders who have specific technical questions.

In his Master's thesis entitled *Advanced Energy Efficient Upgrading for Affordable Homes in Canada*, Lee states that the degree of potential for implementation of energy efficiency in affordable housing remains undetermined. The author deals with cost effectiveness applied to research on the implementation of the R-2000, and Advanced House energy standards. He concludes that it is possible to integrate both energy efficiency and affordability in most cases. However, according to Lee, certain technologies seem to be inappropriate for low cost housing.

Levels of complexity, sophistication or intricacy of projects depend on the availability of research funding. An example of well-funded research potential can be seen in the collaboration of the Florida Solar Energy Center (University of Central Florida) in association with Sandia National Laboratories, the Florida Energy Office, and the Lakeland Electric and Water company. They embraced a project that involved monitoring two identical residential buildings which were purpose-build for the study. The central objective of the project was to test the feasibility of constructing new single family homes engineered to reduce air conditioning loads to an absolute minimum, so that most of the cooling and other daytime electrical needs can be met by the photovoltaics components. Results of this experiment are intended to enhance research in a number of fields about sustainable design and actual building technology improvement.

1.5.1 Renewable energy technologies in the market

In both developed and developing countries, when renewable technologies, such as solar thermal or photovoltaics, have passed laboratory tests concerning performance and quality, they face a new challenge: acceptance and purchase by the consumer. An excellent invention can be lost to its potential target group due to an inadequate marketing strategy. Thus, the role of institutions, research centres, government agencies and private enterprises includes, beyond promotion of the products, marketing studies to identify the features that new technologies need in order to become a suitable option and succeed.

Despite features that would facilitate the use of solar energy (one of the most recommended technologies by ecologists and solar technology developers), solar systems are not accepted by potential customers if they do not prove to be cost effective. John Randolph and Robert P. Schubert developed a model, based on results of a study in Virginia which related system cost, energy performance and energy value for cost-effective solar water heaters. Randolph and Schubert found out that there must be a balance between: a) installed cost, b) annual energy performance (average amount of useful heat collected per square feet; and c) value of conventional energy saved, in dollars per British Thermal Units.

Jane S. Peters and Dave Robinson conducted a study in Wisconsin to identify key market barriers to the installation of solar domestic water heaters (SDWH) systems and to identify program elements for a state-wide effort which would maximise program participation. Market research in Wisconsin included interviews with solar heater owners, homeowners without solar devices and trade allies. Results of their study reveal that SDWH can be marketed to a small segment of the consumer population that is already aware of and interested in solar technology. However, the authors point out that the market segment will only grow if awareness and knowledge of solar technology is increased. The authors conclude that business viability will require reductions in installed cost, availability of low cost financing and some incentive that recognises the extent of public benefits that would result in a reduction in harmful emissions.

The International Energy Agency (IEA), conducted a survey of 15 solar houses in developed countries in Northern Europe, the United States, Canada and Japan to analyse design strategies and innovative technologies. The general conclusion was that passive and active solar strategies together, with the adoption of energy conservation measures and the integration of new material and technologies, can lead to significant reductions in energy consumption in domestic buildings. Nevertheless, in terms of economics, findings are similar to those of Kevin Lee, cited above: A number of innovative technologies and systems for housing are expensive even by wealthy nations' standards.

These findings seem to indicate that sustainable technologies are meant only for developed countries, since that less advanced nations cannot afford them. Technology transfer and affordability are then, issues to consider.

1.5.2 Renewable energy technologies for developing countries

Development of a new technology is meaningless unless it can be used. Nevertheless, technology implementation seems to be a major problem for Third World countries where economical resources are scarce. Lack of resources include education and information access to non-traditional technologies, as well as economic difficulties.

According to the Solar Development Initiative, today approximately 2.3 billion people in the developing world do not have access to electricity and, in about 15 years, the energy demand of these countries may surpass that of industrialised states. Trying to meet this need with conventional fuels is likely to cause serious damage for the ecological balance of the Earth. Thus, implementation of appropriate and affordable technologies is gaining attention from international agencies such as the World Bank (WB). Analysing disadvantages of subsiding energy versus local participation and sector policies, the WB encourages utilisation of renewable resources, especially for rural areas in developing countries. In this field, Eggers-Lura made an exhaustive list of affordable products and methods related to solar energy in the Third World during the 1970s. Unfortunately, it has not been updated since then.

Mobilizing Technology for World Development is a collection of essays presented in the Jamaica Symposium sponsored by the International Institute for Environment and Development that includes various issues concerning technology transfer from developed to developing countries, such as the collaboration between mutual programs of North and South which is intended to enhance efficiency and productivity. Following the same trend, I.M. Badran and R. A. Aburas believe there is a very slim chance for developing countries to succeed except through collective work in regional and sub-regional organizational structures. They point to the co-operation between oil-producing and non-oil-producing countries who are attempting to secure their respective futures with regard to energy, by remodelling their consumption patterns and working out proper solutions. The authors point out that energy requirements and assessments with respect to developing countries are misleading in many instances because they are often processed in developed countries, away from the intended area of implementation and are based on information gathered locally, which lacks accuracy.

The authors of *Problem Solving Using Technology, Economics and Politics* recognize this gap, and emphasize the distinction between the kinds of energy planning applicable to developed and developing countries. The roles of bankers, economists and engineers in advising decision-makers and politicians are outlined, and the sources and end-use of energy in developing countries are tabulated, while the importance of commercial energy to agricultural and industrial development is underlined. Cost benefit analysis methods which are known to be effective and are widely used in decision-making regarding energy options, are detailed. Arguments are developed for the modification of some of the traditional principles when applying this kind of analysis to particular cases.

L.A. Kristoferson and V. Bokalders, from the Beijer Institute of the Royal Swedish Academy of Sciences, believe that programs which address to Third World development should not lump together widely different technologies and methods in different phases of research, development and testing, and that projects must be paralleled by an increased understanding of the complex social and economic issues that influence these technologies. This is the aim of a study that focuses on renewable energy technologies for the rural sector and analyses a number of strategies to substitute fossil fuels. Methodology for the study of each technology comprises identification of the potential consumer nations, an explanation of the physical principles of the technology, as well as economic considerations, environmental impact, development needs, and dissemination studies.

Rahman and Bates point out that the critical issue in technology transfer is utilization of the existing capabilities, development of new human and institutional resources, adaptation of technologies to local circumstances, and meeting the development needs of the population.

Specific housing energy problems are studied by the Lund Centre for Habitat Studies (LCHS). The publication, *Housing Energy and Indoor Environment*, seeks to integrate research and practice, and has developed a theoretical framework of the household as a system: building materials, appropriate design for climate, ways in which the dwelling is used by the occupants, including socio-cultural practices, and energy end-use. The goal is to contribute to better housing, energy efficiency, and living quality in developing countries, through a diversity of projects from the development of local insulation materials, climatically appropriate design, organization of low-cost housing construction, working with users to design ergonomically appropriate kitchens, and developing research potential with co-operating agencies.

It should be highlighted that many developing countries are already playing a key role in technology development and transfer. "North to South" is not the only mode of technology transfer. A number of developing countries are initiating projects which focus on energy efficiency, renewable energy, and the enhancement of technology projects.

A number of regional and national technology and information centres have evolved in developing countries in response to the challenge presented by climate change, and simultaneously a number of technologies have also emerged in both developing and industrialised countries.

McGill University's Centre for Minimum Cost Housing has directed a large number of projects to investigate inexpensive techniques for developing countries. In 1988, Open House International dedicated a volume to the presentation of the Centre's work. Articles presented covered a variety of categories such as innovative building technologies, housing for low-income families and technologies for energy and natural resources saving. The underlying premise of the Centre, as expressed by its founder Alvaro Ortega, and cited by Witold Rybczynski in the journal's editorial, is that the world housing problem is partly due to a lack of appropriate technical solutions. Field experiments have been carried out in cooperation with local research groups in Zambia, the Philippines, Mexico, Guatemala, the United Arab Emirates, and in small communities in northern Canada.

McGill's Brace Research Institute (BRI), has been involved in the technology transfer process to developing countries for more than 40 years. Dr. Tom Lawand, of BRI identifies three principal areas to be studied in order to find a match between what is technologically necessary and what is acceptable within a community: a) traditional energy consumption patterns and needs, b) methods of improving traditional technologies and adapting new technologies to local conditions and c) effective methods of introducing these innovations into the community. Lawand believes that matching the type and quality of the energy supply with the demand ensures a more efficient use of the available energy resource. He also emphasizes the importance of the role of women in energy supply and utilization, and participation in the development of energy systems.

Lawand proposes a methodological approach for integral rural energy systems that in general terms comprise survey and background study, definition of objectives, appropriate technologies selection, project implementation mechanisms, economic analysis, and long-term examination. Lawand's research led him to evolve this model into *Methodological Guides for Renewable Energy System Evaluations*. This work goes into detailed considerations and steps to follow while planning a renewable energy system in developing regions. It defines three major components that comprise the concept of technological sustainability: a) its utility to the community or the individual family, b) its accessibility and, c) its maintainability.

1.6 Intended Audience

This study is directed to architects, engineers, SWH developers (scholars and entrepreneurs), contractors and users. The formers may hopefully find in it a concise and critical tool to back up a purchasing decision.

1.7 Scope of the Study

The study covers the Mexico City Metropolitan Area, which includes the Federal District and the adjacent municipalities. The reason for considering the Metropolitan Area is that it operates as a unique entity, for which decisions regarding planning, politics, and the environment are generally made for the entire area.

1.8 Research Design

The research comprises:

1. Introduction and background information.

- Influential factors
- Rationale for the study

- Literature review

2.Adverse effects of the use of fossil fuels in the MCMA

- Topography and climate in the MCMA
- Health effects of pollutants

3. Identification of the target market

- Water and energy consumption
- Identification of consumers of hot water (domestic and small/medium business, micro-industries)

4. Alternative to the use of fossil fuels and traditional methods for heating water

- Traditional water heating systems in Mexico City
- The energy policy in Mexico and the cost of fuel
- How a solar thermal collector works
- Case study

5. Conclusions

Appendices

Chapter 2: Adverse effects of the use of fossil fuels in the MCMA

2.1 Introduction

This chapter is dedicated to the analysis of the environmental situation of the Mexico City Metropolitan Area (MAMC). Environmental damage to the basin of Mexico is a complex process related to factors such as its geographical location, demographics, over exploitation of natural resources, and intensity of land use, among others. This study is oriented to the various forms of air pollution derived from the use of fuels in the MCMA.

Mexico City and its Metropolitan area are located in the southern portion of the Mexican high plains, in a region called the Basin of Mexico which has a surface of 9,560 square kilometres. It is a closed basin surrounded by mountain ranges and rivers flow from its higher regions to the lower plains, being the source of a series of swamps and lakes[1] (Valverde and Aguilar 19). The Federal District and a portion of the MCMA site are located in an area that, a few centuries ago, was a lake (figure 2.1).

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[1] Although the formal geographically defined as a basin, the plateau, particularly the Federal District and a portion of the MCMA, are often addressed as "The Valley of Mexico".

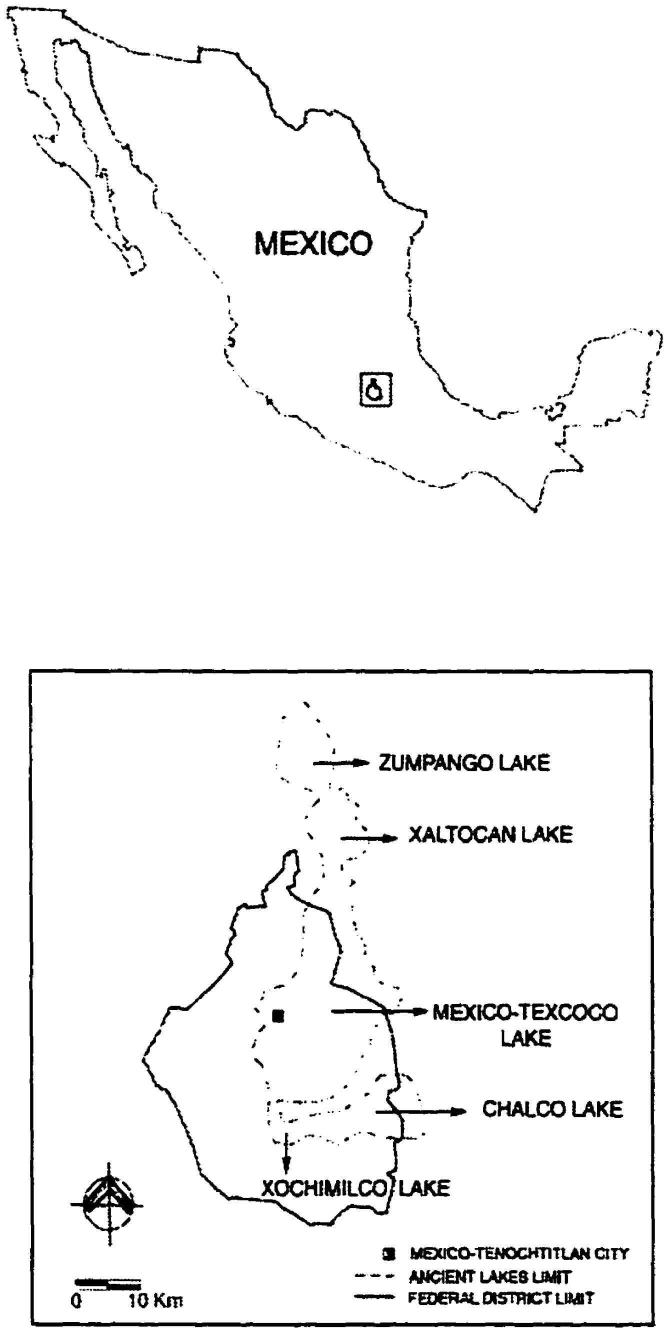


Figure 2.1 Location of the ancient lakes
Source: Atlas de la Ciudad de México

The average altitude of the city is 2,240 metres above sea level. The climate has been defined by Jáuregui as "tropical of the mountains", meaning that, although the temperature is abated by the elevation of the valley, other climatic features, such as the irregularity and intensity of rainfall, are typical of the tropics. On the other hand, during the winter season, the basin of Mexico is under the influence of polar air masses which are representative of mild regions outside the tropics. However, two major seasons can be defined: the dry season occurring between November to April, and the rainy season, which lasts from May to October (Jáuregui, 37). These unique geographic and atmospheric characteristics are determinant for the environmental behavior, and it is particularly related to what is known as the greenhouse phenomenon.

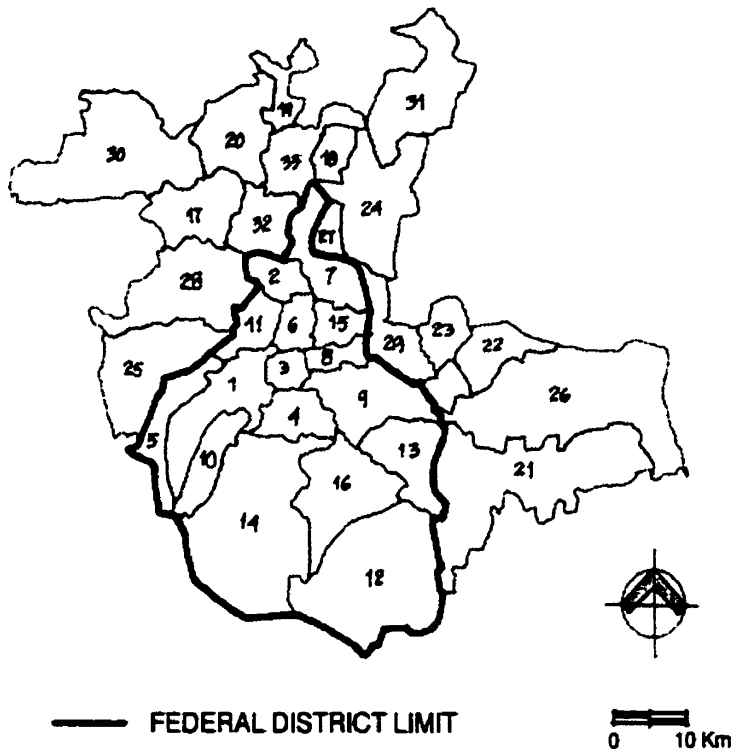
The foundation of the city (México-Tenochtitlan) in 1324, in a small island of the Texcoco Lake still remains a myth. However, since the beginning the city faced the following problems: a) scarcity of drinkable water, b) sparse arable land, and c) the constant threat of floods. Nevertheless, during the ruling of the Azteca Empire, there was an almost absolute hydraulic control of the basin through the use of dams, aqueducts and channels. Huitizlopochtli's temple, a westerly-oriented construction, was the center of the four edges that determined the city layout. This layout was respected by the Spanish conquerors, but the complexity of the urban functions increased upon the arrival of waves of migrants.

The city experienced a period of slow growth from the XVI[th] to the XVIII[th] centuries. However, uncontrolled deforestation and the destruction of the largest dam caused serious ecological problems. The hydraulic system became unstable, floods were frequent, and municipal authorities began to the drain the lakes. As the water levels in the lakes fell, the city began to grow. During the first decade of the XXth century, the area of the city fivefold. The problem of flooding appeared to have been resolved with the creation of the Tajo de Nochistongo, a kind of channel which was engineered to drain the basin, which was preceded by the construction of the deep drainage system. However, the constant drain of water, both to prevent floods and to obtain drinking water, resulted in the sinking of the whole city during the years that followed, and large clouds of dust, which originated in the ancient bottom of the Texcoco lake, were carried to the city by the northeastern winds (Lombardo, 41-71).

The Metropolis began to form when the integration of surrounding municipalities into the urban fabric took place during the Mexico's so-called miracle decades (1940s-1970s). According to Kandell, cited in Pezzoli's work:

> During the Miguel Alemán Valdés presidency (1946-1952) the capital became the hub of a national transportation network. This development involved major investments in airport facilities and railway lines and a fourfold extension of asphalted highways. By the 1940s, Mexico City had the largest consumer market in the country, the most numerous labor force, the greatest concentration of entrepreneurial and managerial talent, the banks and government agencies upon which business depended for credit and permits, and an advanced urban infrastructure (Pezzoli, 128-129).

By 1995, the MCMA had a population of almost 17 million inhabitants and consisted of 4,902.3 square kilometres (INEGI,1999), comprising the Federal District (home of the Government) and 21 adjacent municipalities in the State of Mexico.



Federal District: 1) Alvaro Obregón, 2) Azcapotzalco, 3) Benito Juárez, 4)Coyoacán, 5)Cuajimalpa, 6) Cuahutémoc, 7) Gustavo A.. Madero, 8) Iztacalco, 9)Iztapalapa, 10) Magdalena Contreras, 11) Miguel Hidalgo, 12) Milpa Alta, 13) Tláhuac, 14) Tlalpan, 15) Venustiano Carranza, 16) Xochimilco

State of Mexico: 17) Atizapán de Zaragoza, 18) Coacalco, 19) Cuautitlán, 20) Cuautitlán Izcalli, 21) Chalco, 22) Chicoloapan, 23) Chimalhuacán, 24) Ecatepec, 25) Huixquilucan, 26) Ixtapaluca, 27) La Paz, 28) Naucalpan de Juárez, 29) Netzahualcóyotl, 30) Nicolás Bravo, 31) Tecamac, 32) Tlalnepantla, 33) Tultitlán

Figure 2.2 The Federal District and adjacent municipalities
Source: Atlas de la Ciudad de México

2.2 Air pollution in the MCMA: topography, climate and the use of fossil fuels

Air pollution has been a cause of major concern for local authorities, public health workers and environmental organizations for the past two decades. According to Bisio and Boots, air pollution may be defined as the contamination of outdoor or indoor air by a natural or man-made agent in such a way that the air becomes less acceptable for intended uses, which, in this context, is the maintenance of human health. Although natural pollution sources are sometimes important, most pollution-related health problems result from man-made (anthropogenic) pollution involving mobile sources (e.g., automobiles), outdoor stationary sources (e.g., power plants, smelters, and factories), and various indoor sources (e.g., building materials and combustion). Physically, air pollutants are dispersed into the atmosphere as gases, fibers, or as a suspension of liquid or solid particles in air (aerosols). Gases, in the form of discrete molecules, from true solutions within the air. Fibers are arbitrarily defined as particles having a length at least three times their width. Aerosols may contain particles either of uniform size (monodisperse) or different sizes (polydisperse or heterodisperse). Levels of specific air pollutants at any given location depend on complex interactions of natural and anthropogenic sources which change over time (daily, seasonally, or annually). Local anthropogenic causes often predominate. Thus, pollution patterns and associate health risks vary widely at different times and places because sources and meteorologic conditions continually change. Some community air pollutants are directly released into the air. These are called primary pollutants. Those air pollutants not directly released into the atmosphere but are formed within it by chemical reactions among primary pollutants and normal constituents of air which are known as secondary pollutants (Bisio and Boots, 96).

Primary Pollutants		*Secondary Pollutants*	
Carbon monoxide	CO	Ozone	O_3
Sulfur dioxide	SO_2	Nitrogen dioxide	NO_2
Nitrogen Oxides	NO_x	Peroxyacetyl nitrate	
Nitric oxide	NO	Nitric and nitrous acid	
Nitrogen dioxide	NO_2	Suspended particles	
Volatile organic compounds		Sulfuric acid and sulfate salts	
Suspended particles		Nitrate salts	
Metal compounds		Organic aerosols	
Dusts			
Soots			

Table 2.1 Primary and secondary pollutants.
Source: Bisio and Boots.

In general, coal combustion emits more sulfur dioxide, carbon monoxide, and particles than oil combustion, whereas levels of emission of nitrogen oxides are similar for both fuels. The fate of effluents from fossil fuel[2] combustion depends on the manner in which they are released. Large modern stationary sources, such as electric power plants and smelters, typically discharge through tall stacks. This type of discharge diminishes local pollutant concentrations at ground level and enhances pollutant

[2] A fuel is defined as any substance, solid, liquid or gas, which may be easily ignited and burned to produce heat, light or other useful forms of energy. For example, coal, charcoal, gasoline, kerosene, light oils, fuel oils, natural gas, liquefied petroleum gases, hydrogen, etc.
The principal fuels used in Mexico are basically fossil fuels (hydrocarbons) obtained from oil refining (Environmental Software and Services GmbH).

dispersion, but increases residence and reaction times in the atmosphere, favoring the production of secondary pollutants and regional pollution problems. On the other hand, home furnaces discharge their effluents near roof level, resulting in higher, more localized ground level concentrations (Bisio and Boots, 97).

Combustion is the rapid oxidation (combination with oxygen) of a fuel resulting in the release of usuable heat and, usually, the production of a visible flame. In addition to fuel and the oxidizer, an ignition source is usually needed to begin the process.

Common combustion consists of the following three processes:

carbon + oxygen -------> carbon dioxide + heat
hydrogen + oxygen ------> water vapor + heat
sulfur + oxygen ------->sulfur dioxide + heat

Table 2.2 Combustion Process
Source: Environmental Software and Services GmbH

The city's geographical situation makes the dispersion of air pollutants extremely hard and, depending on climatic conditions, the situation may ease or worsen. According to the Atmospheric Research and Information Centre (ARIC) of Manchester Metropolitan University, the atmospheric pollution in the Mexico City Valley has two primary sources. One is of a natural origin, composed of dust that the winds and vehicles lift from unvegetated and unpaved areas on the outskirts of the city. The second, and most significant, results from the consumption and use of fossil fuels.[3] Figure 2.3 shows Mexico's national energy consumption for 1997.

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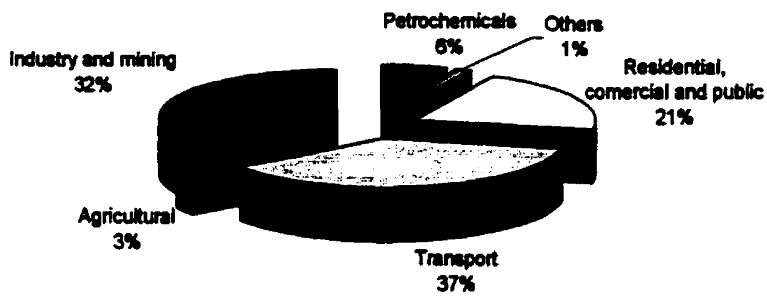
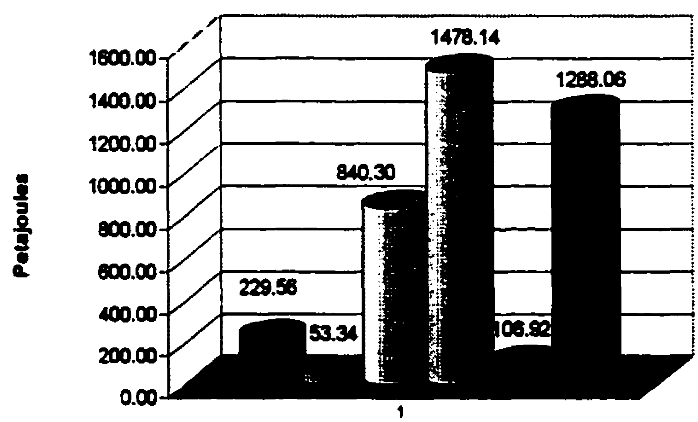
[3] A study made by the Oak Ridge National Laboratory in the U.S. asserts that fossil-fuel carbon dioxide emissions from Mexico grew exponentially at a rate of 7.3% per year from 1891 to 1982. From 1983 to 1989, Mexico's fossil-fuel CO2 emissions were relatively stable. Since 1989, total emissions have risen 24.8% reaching an all-time high of 95 million metric tons of carbon in 1996. Emissions increase was largely attributable to increasing oil consumption (Marland et al.).

National Energy Consumption by Sector 1997





	1
Petrochemicals	229.56
Others	53.34
Residential, comercial and public	840.30
Transport	1478.14
Agricultural	106.92
Industry and mining	1288.06

Total consumption: 4000 petajoules

Figure 2.3 National Energy Consumption in 1997
Source: Secretaría de Energía, Balance Nacional de Energía 1997

According to the National Committee for Energy Savings (CONAE), motor vehicles are responsible for 39 % of the total energy consumption in the MCMA, followed by the industrial and mining sector (36%), the residential, commercial and public sector (22%), and agricultural activities (3%). The largest source of hydrocarbon pollutants is the transport sector which produces up to 54% of total HC emissions, and up to 99% of carbon monoxide emissions, followed by the service sector, with a 39% of emissions (CONAE, 1998).

Gasoline, diesel, combustible oil, and liquefied petroleum gas are the most commonly used fossil fuels in the MCMA.[4] Table 2.3 shows the percentage of total consumption by sector. At first sight, this data may not seem coherent with data provided by CONAE for the MCMA total energy consumption. However, table 2.3 numbers represent only the consumption of fossil fuels, without electricity, and the subdivision per sector has not been done on the same basis. One can assume that the "others" sector includes residential and commercial uses, while "thermoelectric" is usually categorized under the "industry" section.

Percentage of total fossil fuel consumption, 1996

	Transportation	*Thermoelectric*	*Industry and Services*	*Others*	*Total*
Gasoline	38.1				38.1
Diesel	11.0		2.1		13.1
Combustible Oil		4.8		14.5	19.3
LP Gas			2.3	16.8	19.1
Natural Gas		10.4			10.4
Industrial Gas Oil			< 0.1		
Total	49.1	15.2	4.4	31.3	100

Table 2.3 Energy Consumption by Sector in the MCMA
Source: PEMEX Statistics, 1996
Note: Annual consumption in the MCMA reaches the equivalent of 17.33 million cubic metres of Nova Gasoline.

[4] Consumption of natural gas has become increasingly important in Mexico and now accounts for 19% of fossil-fuel CO_2 emissions (Marland et al.).

Figures 2.5-2.9 show pollution emissions[5] by sector in Mexico during 1996. Table 2.4 gives specific information for the industry, services and transport sectors for 1994 in the MCMA, unfortunately, data for the residential sector was not available. It is important to note that, although the transportation sector (especially private automobiles), has been blamed for up to 75% of total pollutants, the industrial sector also emits large amounts of carbon dioxide and nitrogen oxides, and it is the most significant source of sulfur dioxide at 57%. Internal combustion engines produce 27%, and the service sector

[5] Principal pollutants from combustion process by origin are:

Pollutant	Origin
Carbon monoxide and hydrocarbons	Are the products of an incomplete combustion and could be formed when: 1) A fuel rich mixture is burnt. 2) When the fuel and oxidizer are not in full contact. 3) When there is not enough time for the combustion process to be completed. 4) When the temperature in the combustion chamber is not high enough.
Carbon dioxide	Largely a byproduct of energy generation and use. Total emissions consist of the sum of CO_2 produced during the consumption of solid, liquid, and gaseous fuels, and from gas flaring and the manufacture of cement. Gas flaring is the practice of burning off gas released in the process of petroleum extraction. During cement manufacturing, cement is calcined to produce calcium oxide. In the process, 0.498 metric ton of CO_2 is released for each ton of cement production. Combustion of different fossil fuels releases CO_2 at different rates. For the same level of energy consumption, burning oil releases about 1.5 times the amount of CO_2 released by burning natural gas; coal combustion releases about twice the CO_2 of natural gas.
Sulfur dioxide	Is emitted as a consequence of burning fuels that contain sulfur compounds. This is true of standard diesel in Mexico, which is used as fuel by many trucks, buses, and industrial boilers in the country.
Nitrogen oxides (NOx)	Can be formed in three different ways: 1) Thermal-NO_x is produced when combustion occurs at high temperatures (typically above 1000oC) because the nitrogen contained in the combustion air will also react with the available oxygen. 2) Fuel- NO_x is produced when the fuel contains nitrogen compounds which react with the available oxygen. 3) Prompt- NO_x is the way that smaller amounts of NO_x can be produced, and is characterized by the rapid formation of NO_x during the first stages of the combustion process beginning with nitrogen and oxygen from the air.
Particulate matter (TSP)	Can be the consequence of a high ash content in the fuel (in the case of fuel oils), or poor presentation of fuel producing incomplete burning (for solid and liquid fuels).

Sources: Environmental Software and Services GmbH and
Carbon Dioxide Information Analysis Center (CDIAC), Environmental Sciences Division, Oak Ridge National Laboratory.

16%. Sulfur dioxide is emitted as a consequence of burning fuels that contain sulfur compounds (table 2.2), such as diesel, a fuel which is largely used in Mexico (figure 2.4).

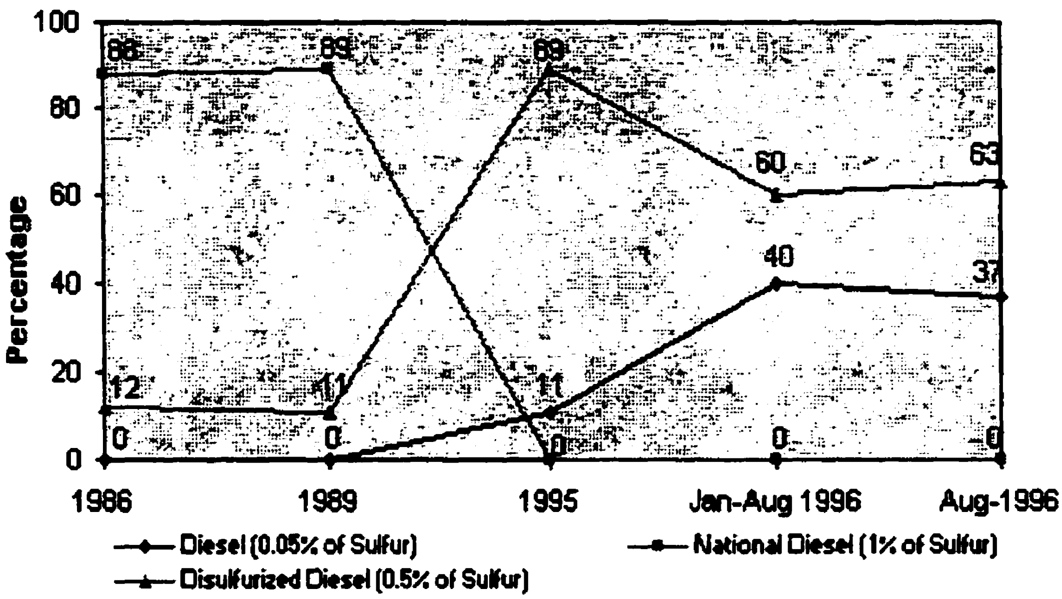


Figure 2.4 National consumption of industrial diesel.
Source: Mexican Institute of Ecology, 1996.

Emissions for the MCMA 1994
(ton/year and weight percentage by pollutant)

	*TSP**		*SO_2*		*CO*		*NO_x*		*HC*		*Total*	
	Ton/ year	%	Ton/ year	%	Ton/ year	%	Ton/ year	%	Ton/ year	%	Ton/ year	%
Industry	6,358	1.4	26,051	57.3	8,696	0.4	31,520	24.5	33,099	3.2		3
Services	1,077	0.2	7,217	15.9	948	0.1	5,339	4.2	398,433	38.9	413,014	10
Transportation	18,842	4.2	12,200	26.8	2,348,497	99.5	91,787	71.3	555,319	54.1	3,026,645	75
Vegetation and Soil	425,337	94.2	0	0.0	0	0.0	0	0.0	38,909	3.8	464,246	12
Total	451,614	100	45,468	100	2,358,141	100	128,646	100	1,025,760	100	4,009,629	100

*Total Suspended Particles

Table 2.4 Polluting emissions for the MCMA 1994
Source: Mexican Institute of Ecology, 1996

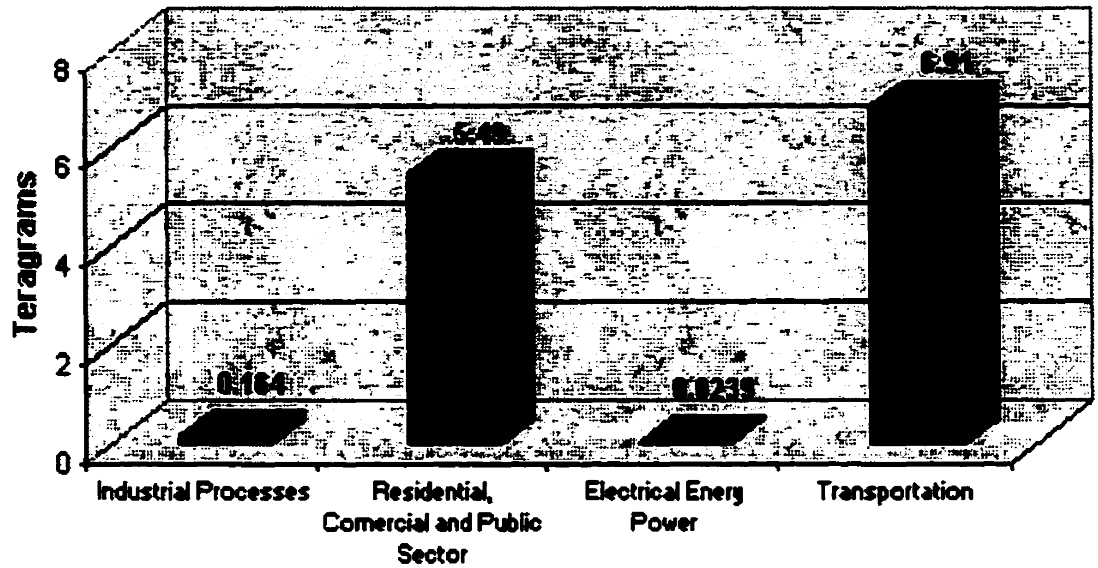


Figure 2.5 Emissions of CO by sector
Source: Mexican Institute of Ecology, 1996

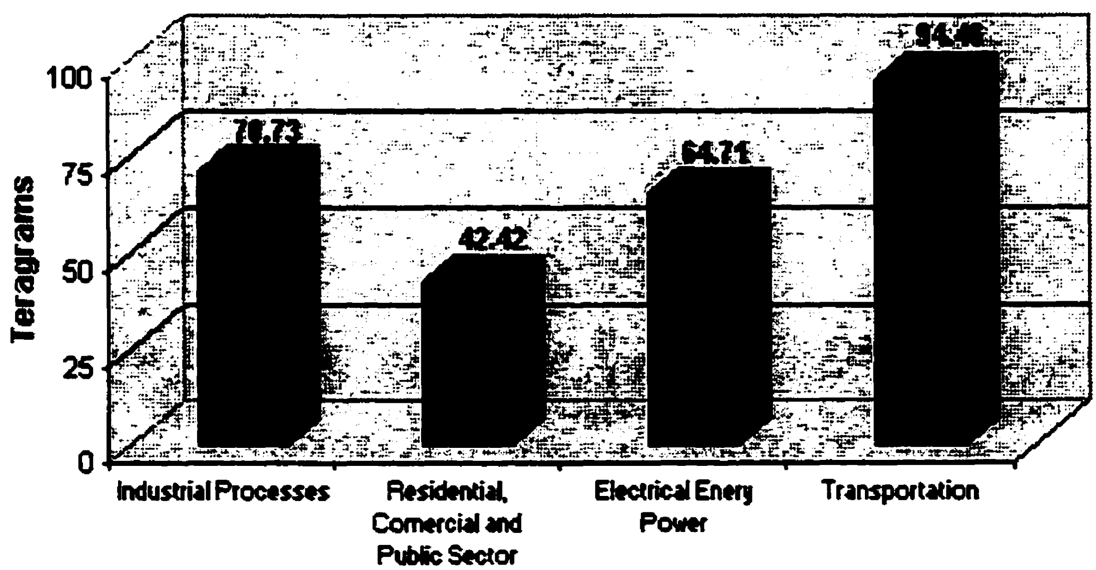


Figure 2.6 Emissions of CO2 by sector
Source: Mexican Institute of Ecology, 1996

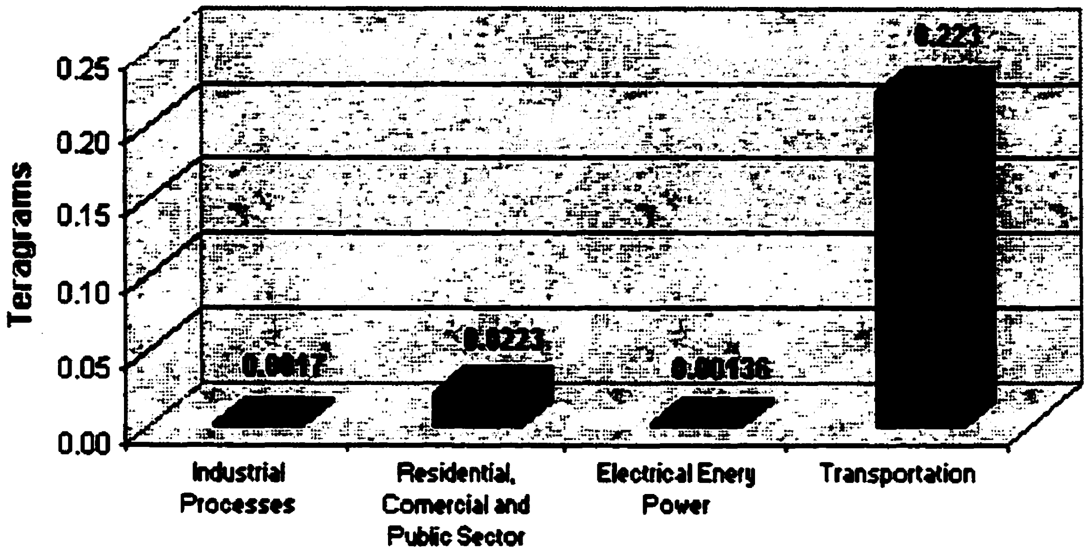


Figure 2.7 Methane emissions by sector
Source: Mexican Institute of Ecology, 1996

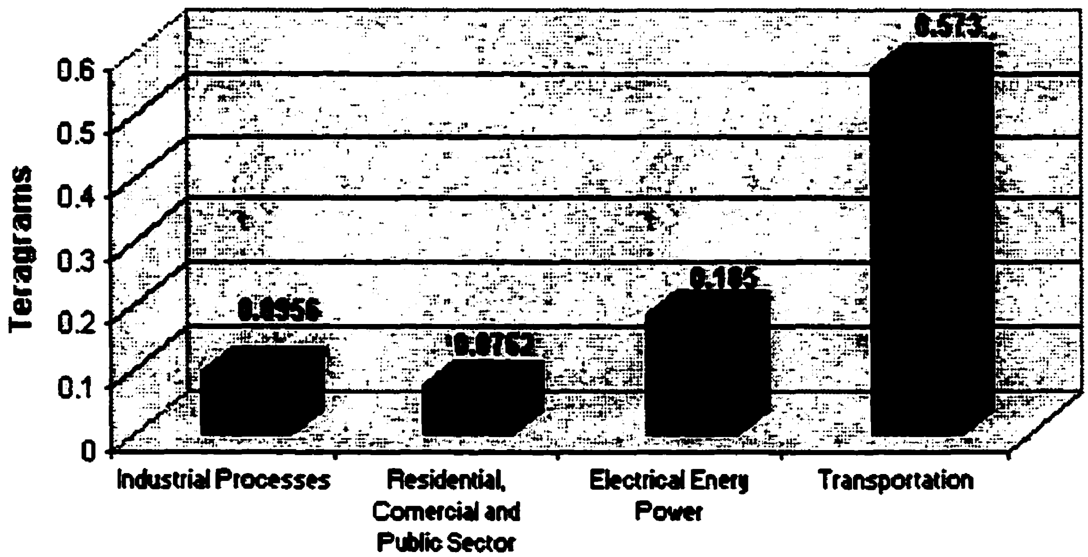
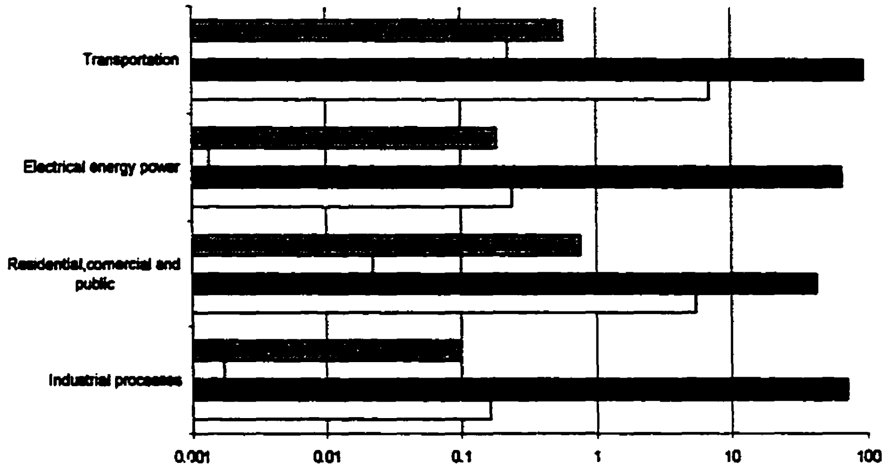


Figure 2.8 Nitrogen Oxides emissions by sector
Source: Mexican Institute of Ecology, 1996



	Industrial processes	Residential,comercial and public	Electrical energy power	Transportation
NOx	0.0966	0.762	0.165	0.573
Methane	0.0017	0.0223	0.00136	0.223
CO2	70.73	42.42	64.71	94.46
CO	0.164	5.49	0.239	6.91

Figure 2.9 Pollutant emissions in Mexico 1996
Source: Mexican Institute of Ecology, 1996

The ARIC stresses that, because the city is situated at an altitude of 2,240 m, its atmosphere contains 23% less oxygen than is found at sea level. This leads to the creation of more pollution as a result of incomplete combustion processes. The effect of altitude is particularly problematic in terms of carbon monoxide (CO) pollution, as altitude not only increases the production of CO but also increases its negative effects on health especially among highly sensitive population groups, such as children, pregnant women, the elderly, and asthmatics. The high altitude also causes constant thermal inversions[6] which trap pollution within the city. During winter (November - May) inversions can occur up to 25

[6] Thermal inversions or *greenhouse effect*, which Bisio and Boots define as the temperature enhancement produced by the absorption of solar energy by the earth's surface and re-emitted as longer wavelenght infrared radiation. Certain gases in the atmosphere, primarily water vapor and to a lesser degree CO_2, have the ability to absorb the outgoing infrared radiation which is translated to heat. Therefore, there is concern that increasing concentrations of CO_2 and other trace greenhouse gases due to human activities will enhance the greenhouse effect and cause global warming (Bisio and Boots, 36).

days each month. The city receives intense solar radiation all year round, which accelerates the formation of ozone. The local topography, meteorology and high emissions of precursor pollutants make Mexico City and its surrounding area an almost ideal place for the generation of ozone. Indeed, ozone levels in Mexico City are exceptionally high and present a problem for all areas of the city.

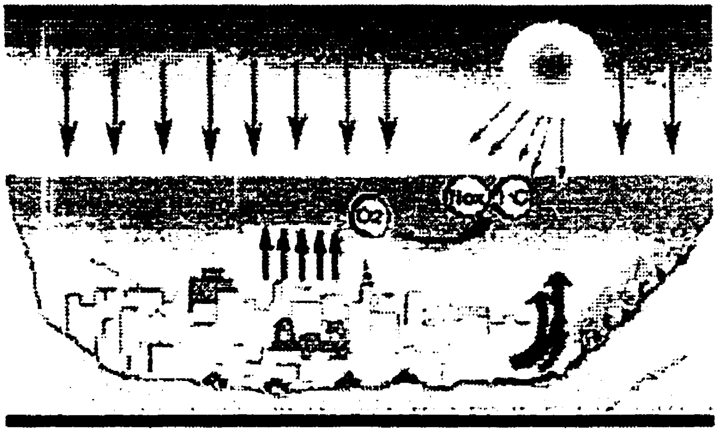


Figure 2.10 The greenhouse effect in the MCMA
Source: Environmental Software and Services, 1988

Gas		Principal source	Atmospheric Residence Times Years
Carbon dioxide	CO_2	Fossil fuel combustion, deforestation oceans, respiration	120
Ozone	O3	Photochemical reactions in the troposphere, transport from stratosphere	NA
Chlorofluorocarbons	CFC-11	Manufacturing of foam, aerosol propellant	55
	CFC-12	Refrigerant, aerosol propellant, manufacturing of foams	116
	CFC-113	Electronics solvent	110
Hydroclhorofluorocarbons	HCFC-22	Refrigerant, production of fluoropolymers	16
Methychloroform	CH3CCl3	Industrial degreasing solvent	6

Table 2.5 Selected greenhouse gases.
Source: Bisio and Boots.

2.3 Health effects of pollutants

According to Bisio and Boots, concern about the health risks of air pollution reflects the frequency of exposure to numerous pollutants in various environments, the diverse mechanisms by which these pollutants might cause health effects or diseases, and the wide range of susceptibility to pollutants in the population. Humans typically inhale 10,000 to 20,000 liters (11 to 22 kilograms) of air daily, so that doses of pollutants inhaled at even low concentrations may become biologically significant with sustained exposure.[7]

Adverse respiratory health effects (medically significant changes)	***Examples***
• Interference with normal activity of the affected person or persons • Episodic respiratory illness • Incapacitating illness • Permanent respiratory injury • Accelerated or premature respiratory dysfunction	• Transient shortness of breath due to asthma, requiring interruption of work or school • Increased frequency of full-blown asthma attacks, requiring medical attention • Acute bronchitis or shortness of breath requiring bed rest • Pulmonary fibrosis resulting from repeated lung inflammation • Statistically lower average lung function in population groups with higher exposure levels.

Table 2.6 Pollution effects over health
Source: Bisio and Boots.

[7] Exposure is defined as contact between the body and the external environment containing the agent of concern. Exposure is one (but not the only) important determinant of the dose of an agent at target sites in the human body. Important components of exposure are the concentration of the agent in inhaled aire, the duration of inhalation of the contaminated air, and the ventilation rate (volume of air inhaled per unit of time) during the period. The same exposure may be achieved by various combinations of concentration, duration, and ventilation rates. However, short-term peak exposures may elicit biological effects that are different from that observed in the longer-term, lower-level exposures with the same product of concentration, time, and ventilation rate (Bisio and Boots, 101).

The respiratory tract of humans possesses important physical, chemical, and immunologic defense mechanism for clearing and detoxifying inhaled agents. However, the defense systems may be impaired by disease, overwhelmed by large pollutant doses, or may not be fully effective during long-term exposures (Bisio and Boots, 100).

Inhabitants of the MCMA have endured for years long-term exposures to air pollutants. Figure 2.11 shows the percentage of days per year in which national standards for air pollution were exceeded (see tables 2.4 and 2.5). Data is provided by the Mexican Institute of Ecology (INE) for four urban settlements: the MCMA (ZMVM in the chart), Guadalajara, Monterrey and Toluca. The MCMA has faced critical environmental conditions during the last decade, with 1994 being the worst year.

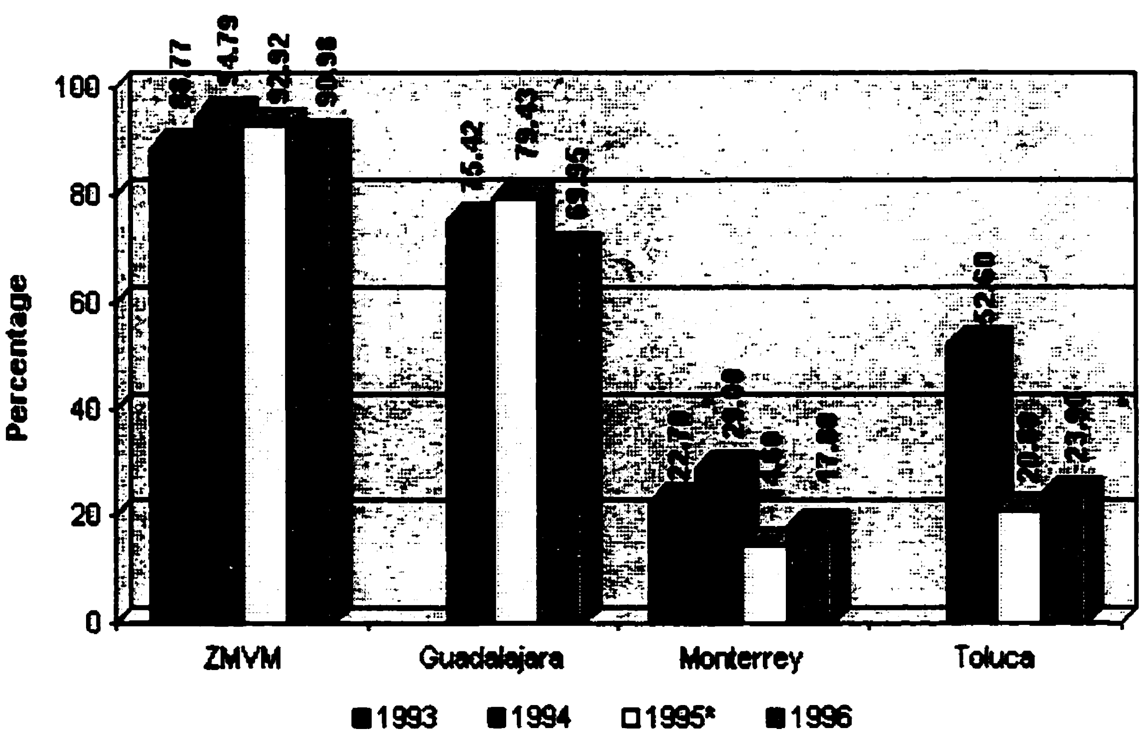


Figure 2.11 Percentage of days exceeding standards.
Source: Mexican Institute of Ecology, 1996.

Pollutant	Values		
	Immediate Exposure		Cronic Exposure
	Concentration and Timeframe	Maximum Aceptable Frecuency	Public Health
Ozone (O_3)	0.11 ppm (1 hour)	Once every 3 years	-
Sulfur Bioxide(SO_2)	0.13 ppm (24 hours)	Once every year	0.03 ppm (annual arithmetic average)
Nitrogen Bioxide (NO_2)	0.21 ppm (1 hour)	Once every year	-
Carbon Monoxide (CO)	11 ppm (8 hours)	Once every year	-
Total Suspended Particulates (TSP)	260 µg/m³ (24 hours)	Once every year	75 µg/m³ (annual arithmetic average)
Particulates less than 10 microns (PM10)	150 µg/m³ (24 hours)	Once every year	50 µg/m³ (annual arithmetic average)
Lead (Pb)	-	-	1.5 µg/m³ (3 month arithmetic average)

Table 2.7 Criteria for Air Quality Standards
Source: Federal Official Daily - December 23, 1994

IMECA	*PST (24hr) µg/m³*	*PM10 (24hr) µg/m³*	*SO2 (24hr) ppm*	*NO2 (1hr) ppm*	*CO (8hr) ppm*	*O3 (1hr) ppm*
100	260	150	0.13	0.21	11	0.11
200	546	350	0.35	0.66	22	0.23
300	627	420	0.56	1.1	31	0.35
400	864	510	0.78	1.6	41	0.48
500	1000	600	1	2	50	0.6

Table 2.8 IMECA Criteria Levels
Source: Federal Official Daily - December 23, 1994

A comparative study between Mexico City and Vancouver pointed out that there was a positive strong association with total mortality in Mexico City for inhalable particles (PM10) and an association between daily mortality and ozone (Vedal et al.). Similarly, a number of studies have proved that long exposure to high concentrations of polluted air (especially sulfur dioxide, carbon monoxide, and lead) can cause severe injuries in the fetus and in children under the age of five. Other possible damages to human health are listed in table 2.9.

Pollutant	*Effects*
Sulfur dioxide	Toxic even at low concentrations. At between 0.15 to 0.25 ppm (parts per million) and an exposure time from 1 to 4 days, or from an equivalent exposure to 1 to 2ppm over 3 to 4 minutes, the effect on normal people is cardiovascular distress. An hour of exposure at a level of 5ppm can produce breathing difficulties; at 10ppm lung damage and nosebleeds can occur.
Carbon monoxide	Acts in the blood to produce carboxyheoglobine, which inhibits the blood's ability to carry oxygen. Concentrations of between 4 and 5% cause headaches due to oxygen deficiency while concentrations of around 10% begin to affect heart function; vision is impared, along with manual skills and learning abilities. Higher concentrations may produce death.
Nitrogen dioxide	Increases the risk of respiratory disease at levels above 0.062 to 0.109 ppm over a 2 to 3 year exposure period. A concentration of 0.12ppm produces an unpleasant odour (immediate perception).
Ozone	Causes various effects depending on exposure conditions. Most common symptoms are coughing, reduced athletic performance, increased nasal permeability, nasal inflammation, and accelerated tracheo-bronchial flow of particles.

Table 2.9 Effects on human health by pollutant
Source: Environmental software and Services GmbH

2.4 Conclusions

Effects associated with exposure to air pollutants in individuals vary largely from relatively trivial health problems, such as eye irritation, headaches, skin irritation and fatigue, to those which can have a serious impact on the respiratory tract. Fortunately, not all levels of exposure are life-threatening. However, even the minor effects can have an impact on spontaneous human activities such as walks, exercise, outdoor recreation, and the general productivity of the population. Numerous times a year, during the so-called environmental emergencies, local authorities call parents and teachers to cancel outdoor activities at schools or home, and cars without catalytic converters are banned from circulation.[8] However, it is only during extreme adverse conditions (stack wind effect or severe thermal inversions), that industries are asked to reduce their productivity in order to decrease emissions into the atmosphere. Alleged loss of capital and lower productivity rates by industries make it difficult to enforce this policy.

Both government and non-government organizations have tried in recent years, through a variety of strategies, to enforce the rational use of energy by all sectors. Tactics such as television and radio campaigns to educate people about the importance of water and energy conservation, and fines imposed on the owners of pollutant equipment and vehicles, as well as the promotion of the use of renewable resources to satisfy energy demands, have been employed at different times.

[8] The "One day without car" policy did not have the positive results as expected. In fact, it stimulated the purchase of subsequent vehicles, depending on the family income and needs.

Petróleos Mexicanos (PEMEX), the government owned company responsible for the exploitation, refining and commercialization of oil, claims to have tightened its environmental policies designed to reduce damage to the ecosystems during the extraction and processing of oil. At the same time, PEMEX has reduced the amounts of lead and sulfur in fuels. However, consumption and emissions are still at a high level and may continue to rise over the following years. Thus, further measures should be taken to prevent future and more severe degradation of the environment.

Statistics show that transportation –especially automobiles—causes the highest levels of pollution of any other sector in the city. The use of the automobile is difficult to discourage, and a considerable amount of work has been done on reducing levels of pollution from internal combustion engines. Other areas of consideration would be the industrial, residential, commercial, and public sectors. Industry is the second largest consumer of total energy in the country, and in the MCMA it represents 57.3% of sulfur dioxide and 24.5% of nitrogen oxides emissions. Domestic, commercial and public is the third use of energy in Mexico. The service sector counts alone for 38.9% of hydrocarbon and 15.9% of sulfur dioxide emissions.

Decreasing the regular combustion processes that these sectors require for routine operation could reduce airborne pollution. Water heating is one of the regular uses of energy and it is accomplished by the burning of fossil fuels. The introduction of an alternative water heating system that does not require burning fossil fuel could, therefore, reduce polluting emissions. Solar water heaters satisfy this condition, and could be used to provide hot water for residential, commercial, public and industrial use. However, water itself is a resource that requires energy to be processed and distributed for domestic and industrial use. Among the multiple uses for water, some activities require larger quantities of water than others. Thus, the availability of hot water needed for each sector depends on the amount of processing required for its use. In order to determine which enterprises require the most hot water in the MCMA, the next chapter analyses the relationship between water and energy, the struggle to supply potable water to Mexico City, and the consumption patterns for a number of industrial, commercial, public and residential activities.

Chapter3: Identifying the target market

3.1 Introduction

In order to determine the possible niche for a large-scale introduction of solar water heaters in the Mexico City Metropolitan Area (MCMA), it is necessary to identify domestic requirements, as well as industrial or commercial activities that require hot water. However, it is essential to understand the complex cycle involved in the supplying of fresh water.

This chapter analyses both the provision and the use of water in urban settlements with particular emphasis on the MCMA. Although hot water intended for domestic use is the biggest user of solar thermal technology, the aim of this discussion is to demonstrate that there is a potential market for solar water heaters in the commercial and industrial sectors in Mexico City.

3.2 Water and energy

3.2.1 Water for urban settlements

According to the World Resources Institute (WRI), the renewable supply of water is defined as the surface water runoff from local precipitation, the inflow from other regions, and the groundwater recharge that replenishes aquifers. Apart from human use, water is also needed to sustain the natural ecosystems found in wetlands, rivers, and the coastal waters into which they flow (World Research Institute, 301-7).

Availability of water constitutes a major and growing problem in many countries of the world. We need water for domestic use, for agriculture, industry, power generation, fishing, forestry, transport and recreation. McNeill states that the basic domestic requirement is about 50 liters per person per day —less than 20 cubic meters per capita per year. By contrast, requirements for industry are much greater. In many developed countries, water use far exceeds 1000 cubic meters per capita per year. Falkenmark and Lundqvist, quoted by McNeill, have identified four crucial scenarios related to water supply: a) water-deprived regions unable to achieve food self-reliance, b) decreasing usability of available water (pollution of surface and groundwater), c) upstream/downstream competition for the water passing through a river system, and d) growing competition for water between urban and rural users. However, McNeill states that competition for water goes even further. He talks about competition between uses and between users: between different sectors and different groups of people, and with regard to the quantity and quality of water available. For McNeill, non-domestic uses of water are "alternative uses, which become competing uses if there is not enough for all to be satisfied." He also identifies three main components necessary for the operation of a drinking water supply system: transmission, treatment, and distribution.

> *Transmission* improves access, and may improve reliability if the water is brought from a more distant and more reliable source. *Treatment* improves

quality. *Distribution* improves convenience, by bringing water right to the house.

Each of these requires investment, and the money — both for the initial investment and, equally important, routine maintenance and regular operation — will have to come from somewhere (McNeill, 253-61).

McNeill's reference to the economic issue of water converges with Falkenmark and Lindh. They state that the fundamental importance of easy access to water leads to the hypothesis that many of the less-developed countries would be found in water-deprived regions in the tropics and subtropics. Falkenmark and Lindh demonstrate that the poorest nations are geographically located where the following phenomena take place: a) water is scarce for part of the year, b) countries experience intermittent drought years, or c) experience a high evaporative demand, which prevents much rainfall from being used in human activities, since most of it returns to the atmosphere. Their work also determines that water scarcity can be overcome by access to the fundamental factors in development stressed by Cox: knowledge, energy, and money (Fallenmark, 80-91).

Table 3.1 describes the annual withdrawal of water per capita per year and the percentage of use per sector for a number of countries throughout the world. In the case of developing countries, one can observe that, when water is scarce, it is mostly designated for domestic and agricultural purposes. More highly developed and industrialized countries have both high per capita withdrawals and a highest allocation of water for their industries. However, according to the WRI, during the past twenty years there has been a reduction in the quantity of water used per unit of industrial product in the developed world, and in a few developing countries. This reduction may be seen as a secondary benefit of measures taken to prevent industries from polluting.

Country	Annual Withdrawals Per capita (cubic meters)	Sectorial Withdrawals (percent) Domestic	Industry	Agriculture	cubic km
Africa					
Madagascar	1584	1	0	99	16.3
Egypt	956	6	9	85	56.4
Congo	20	62	27	11	0.04
Zaire	10	61	16	23	0.36
Europe					
Estonia, Rep	2907	5	92	3	3.3
Bulgaria	1544	3	76	22	13.9
Romania	1134	8	33	59	26
Russian Federation	790	17	60	23	117
Netherlands	518	5	61	34	7.81
Spain	781	12	26	62	30.75
Sweden	341	36	55	9	2.93
Switzerland	173	23	73	4	1.19
Albania	94	6	18	76	0.2
America					
United States	1870	13	45	42	467.34
Canada	1602	18	70	12	45.1
Mexico	*899*	*6*	*8*	*86*	*77.62*
Cuba	870	9	2	89	8.1
Haiti	7	24	8	68	0.04
Brazil	246	22	19	59	36.47
Guyana	1812	1	0	99	1.46
Chile	1626	6	5	89	16.8
Argentina	1543	9	18	73	27.6
Colombia	174	41	16	43	5.34
Asia					
Turkmenistan, Rep	6390	1	8	91	22.8
Iraq	4575	3	5	92	42.8
Kazakhstan, Rep	2294	4	17	79	37.9
Azerbaijan	2248	4	22	74	15.8
China	461	6	7	87	460
Singapore	84	45	51	4	0.19
India	612	3	4	93	380
Indonesia	96	13	11	76	16.59
Cambodia	64	5	1	94	0.52
Oceania					
Australia	933	65	2	33	14.6
New Zealand	589	46	10	44	2

Table 3.1 Annual Withdrawal in selected countries.
Source: World Resource Institute, 1995

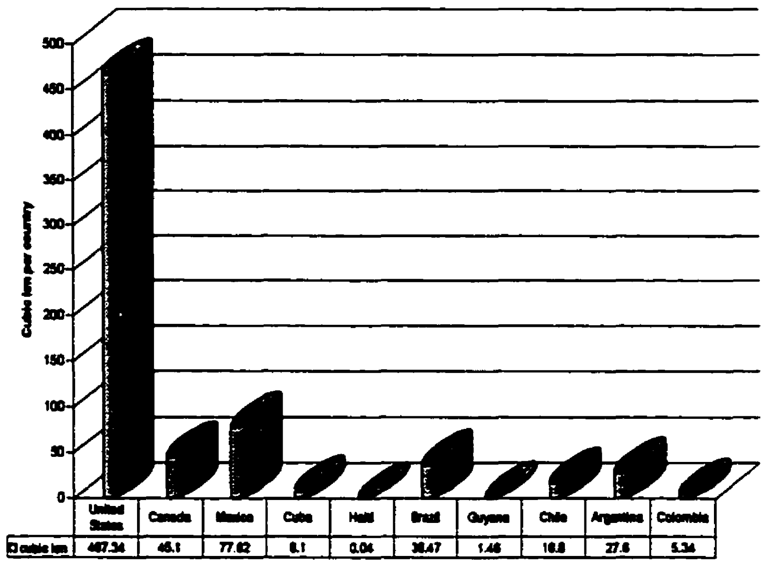


Figure 3.1 Annual Withdrawals in North and Latin America
Source: World Resources Institute, 1995.

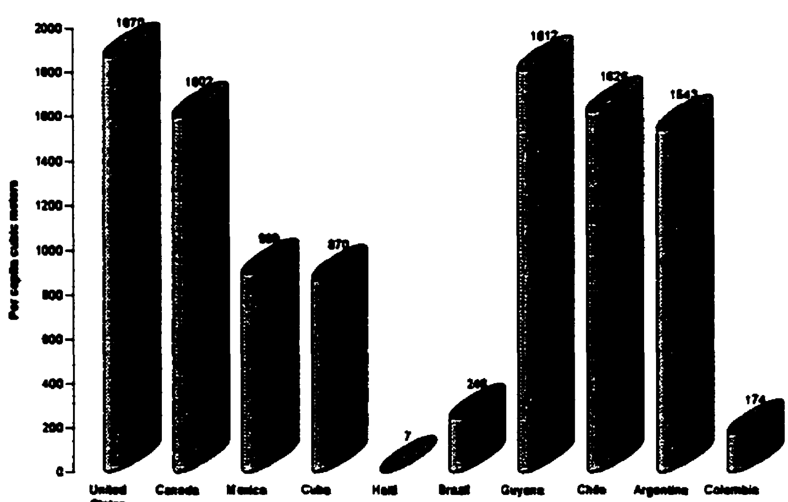


Figure 3.2 Annual Withdrawal in North and Latin America
Source: World Resources Institute, 1995.

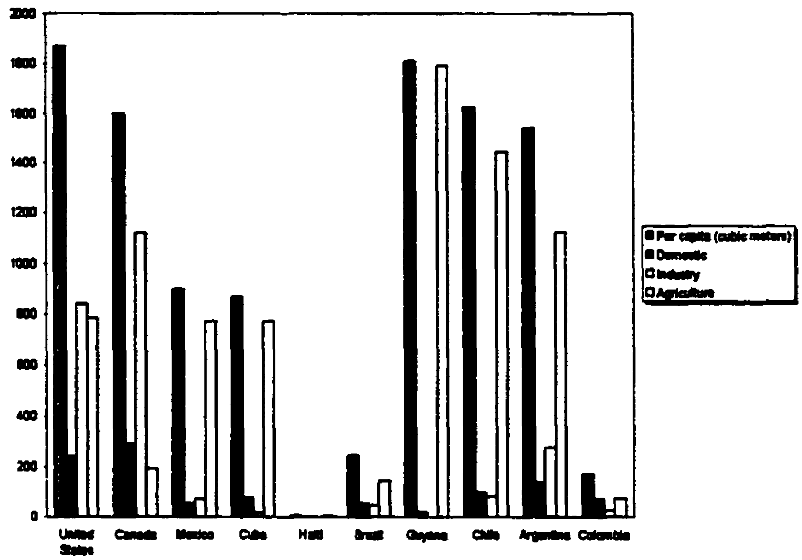


Figure 3.3 Annual per capita withdrawals per sector in North and Latin America
Source: World Resources Institute, 1995.

3.2.2 Water and energy consumption

The efforts made to supply water to large urban settlements support the views of Gleick, who asserts that water and energy are intricately connected; the production, transportation, and cleaning of water, all require the use of energy. Energy allows the processing of water that was previously considered either non-potable or unobtainable. It is now possible to remove salts and other contaminants from water employing desalination and wastewater treatment techniques, and to pump water from deep underground aquifers or distant sources. When the demand for water in a region increases beyond the ability of the region to supply it, new and more remote sources of water must be tapped. These projects almost always involve a substantial investment of energy. To lift $100m^3$ of water per minute to a height of 100 m requires over 1.5 MW of electrical power, if the pumps are 100% efficient. To do this continuously for a year using electricity from a typical oil-fired power plant, with pumps that are 50% efficient would require the energy content of 50,000 barrels of oil (Gleick, 67-79).

On the other hand, water is an essential to the production of energy. To produce electricity, the majority of countries around the world use the combustion of oil, coal and natural gas as their first choice, and hydroelectric facilities as their second one. Withdrawals for cooling thermal electric power plants have increased in the past two decades as the demand for electricity grows. In the United States, about 47% of water withdrawals were directed to this field, and even though net total consumption counted only as 2.9%, remnant water was polluted in a certain degree during the process (Thompson, 126-7). The "blowdown" or wastewater produced by cooling towers is returned to rivers and lakes at a higher temperature, which causes damage to the regional ecology. The construction of dams to provide hydroelectric facilities also has a number of harmful effects on ecosystems.

Gleick has analyzed a number of energy-producing technologies and their relationship to water consumption. A summary of his findings shows that:

1. The creation of reservoirs displaces wildlife and replaces a flowing water ecosystem with standing water. The storage of water in a reservoir leads to consumptive water losses from evaporation and seepage (estimated at an average of 5%). This water represents the loss of a resource that would

otherwise be available for downstream human and ecological uses. Furthermore, when hydroelectric facilities are shared by two or more nations, political conflicts car arise.

2. Industries dedicated to the exploitation of coal are among the most intensive users of water. Water is required for mining, reclamation of mined land, and coal combustion, which requires a substantial water for cooling, ash handling, and waste disposal.
3. The production of oil and natural gas, also require the use of large amounts of water, either for the refining or the cooling process.
4. Oil, shale, and tar sand water consumption come from waste disposal, processing, power generation, and land reclamation. Wastes represent a constant threat to natural waterways.
5. Nuclear power demands large amounts of water for milling, refining and enriching uranium, and for the functioning of cooling process. The current generation of nuclear plants is less efficient than fossil fuel plants because of technological characteristics, restrictions on maximum steam temperatures, and because fossil fuel plants emit a substantial amount of waste heat through the flue gases. A typical nuclear plant operating at 31% efficiency requires much more water for cooling than a comparably size fossil fuel plant. Finally, low-probability, but high-consequence accidents associated with nuclear plants also have an impact on water resources. The meltdown or burning of a reactor core could result in long-term radioactive poisoning of land and water supplies.

6. Geothermal resources are currently considered to be technologically and economically feasible. The "flash conversion" technology is the simplest and least costly of liquid-dominated systems. In this method, a high temperature geothermal fluid is brought to the surface under pressure, where it "flashes" into steam to drive a turbine. Such systems are in use in Italy, Iceland, Mexico, New Zealand, the Philippines, and the United States. Flash geothermal systems also use geothermal condensate for cooling whenever possible, thus, minimizing outside water requirements.
7. Estimates for water consumption in solar thermal power stations, which are used to produce electricity on a large scale, vary considerably in range, depending on the type of facility. Most published estimates are low, around 1 m^3 per 10^3Kwh of electricity. However, the Luz corporation of California provides consumption data as over 4 m^3 per 10^3Kwh(e) and the California Energy Commission made an estimate for make-up water for cooling and evaporative losses from solar ponds of about 25 m^3 per 10^3Kwh(e).
8. Electricity generated by photovoltaics cells use a negligible amount of water.
9. Wind energy facilities require no water for the production of electricity, and almost none for the construction and erection of the wind turbines (Gleick, 67-79).

At the end of his analysis, Gleick concludes that increasing energy use in developing countries through traditional expansion of fossil fuel combustion will lead to severe environmental problems and enormous increases in the consumption of water.

To summarize, it is evident that there is a strong relationship between water and the generation and use of energy. As the world's population grows, do does the demand for water needed for human consumption and other uses. In many regions, local water resources are often insufficient, and therefore water must be piped from distant locations. A typical water supply system involves transmission, treatment and distribution. Each step implies the use of energy and economic resources that vary according to a number of factors like the availability of water in the area and the distance between the water source and the place to be delivered.

According to the World Resource Institute, Mexico is after the United States, the highest consumer of water on the American Continent. Mexico's annual usage amounts to 899 cubic metres per capita (77.62 km3), distributed among three main areas as follows: domestic use, 6% (4.66 km3), industry 8% (6.21 km3), and agriculture 86% (66.75 km3). However, water consumption patterns are not the same for the whole country. The next section of this study looks more closely at the water provision and demand in Mexico City.

3.2.3 Water for 20 million: the case of the MCMA

Water resources in Mexico vary according to region. Saade states that the annual per capita availability is about 5000 cubic meters. However, she remarks that the geographic distribution of the economic activity and population in Mexico does not always correspond to that of the country's rivers and aquifers (Saade, 185-192). While over 76% of the Mexican population live in the north of the country, only 20% of the water resources of the country are available there. Furthermore, there is a big difference between the supply of fresh water in urban and in rural communities. According to the National Water Commission (CNA), in 1995 84% of Mexico's total population had access to drinking water and 67% to sewerage services, yet these numbers did not reveal the fact that only 52% of the rural population had treated drinking water and a mere 21% has access to sewerage services.

The Mexico City Metropolitan Area (MCMA) consists of two political and administrative entities: the Federal District and the peripheral urban municipalities of the State of Mexico. Management of water and wastewater service within the MCMA is shared by the Federal District and the State of Mexico, who are each responsible for providing potable water and wastewater collection and disposal within their jurisdictional boundaries. It is estimated by the National Institute of Statistics, Geography, and Informatics (INEGI), that 22% of the Mexican population lives in the MCMA, and as much as 30% of the industry is located there.

According to the National Research Council, the MCMA receives approximately, 60 cubic meters per second (cms) of water that comes from three main sources: the Cutzamala system, the Lerma river and the aquifer underlying the City. Approximately 43 cm, or almost 72 percent of the water used, is drawn from various well fields that tap the aquifer throughout the Basin of Mexico (Table 3.2).

Surface water within the Basin of Mexico contributes only about 2 percent (1.4 cms) of the water supply for the MCMA. The Magdalena River supplies water to the Federal District, whereas the Madin Dam on the Tlalnepantla River supplies the State of Mexico. Small, naturally occurring springs and streams are used where available, and these sources also enter the distribution system directly.

Raw Water Sources	*Federal District*	*State of Mexico*	*Total*
Basin of Mexico well fields	22.7	20.3	43
Magdalena River	0.2		0.2
Madin Dam	0.5	0.5	0.5
Springs, streams		0.2	0.7
Imported Sources			
Cutzamala River	7.6	3.0	10.6
Lerma well fields	4.3	1.0	5.3
Total Water Supply	35.3	25.0	60.3

TABLE 3.2 Source and Quantity of Water for MCMA Service Areas.
All values are in cubic meters per second (CMS).
Sources of information: Departamento del Distrito Federal, 1992; Comisión Estatal de Agua y Saneamiento, 1993.

The Cutzamala-Lerma System draws 10.6 cubic meters per second (CMS) of water from the Cutzamala River, which is located about 130 km from Mexico City and at a lower altitude (1000 m below the city level)[1]. After treatment near the withdrawal points, the Cutzamala River water is transported by aqueduct. Ground water imported

[1] The average altitude of Mexico City is 2240 meters above the sea level.

from the Lerma Basin (4.3 CMS) is disinfected with chlorine and added to the same aqueduct before the water reaches the MCMA distribution system. A separate aqueduct supplies the State of Mexico service area with 1.0 CMS of ground water from the Lerma Basin. The whole process involves high pumping costs, however, due to a subsidiary system, the real cost of water is not transferred to consumers. Quadri de la Torre has made a calculation of the amount of energy used by the system for a year: he calculates that in 1992 it took 3.4 million barrels of oil to supply the energy needed to pump, lift, and transport the water from Cutzamala. The cost was $US60 million, representing 6 percent of the total energy budget in Mexico City, including the energy budgets of industry, services, residential and transport (Pezzoli, 59).

According to the National Research Council, high water subsidies have allowed access to unlimited quantities of water at an artificially low cost. Because industries consume large amounts of water, these subsidies have served to encourage industrial development within the MCMA. Hence, subsidies led to greater consumption and have contributed to a depletion of water resources. This situation is not unique to Mexico, as low cost water has, until recently, been a common arrangement worldwide. Water subsidies have always been popular when governments wished to promote local economic development. Subsidies have also been defended as anti-poverty policies.

Table 3.3 shows the cost of water in the MCMA.

Water rates for non-domestic (industrial and commercial) users		**Water rates for domestic users**	
Bimonthly Consumption (cubic meters)	Cost per cubic meter	Bimonthly consumption (cubic meters)	Cost per cubic meter
up to 30	$0.40	Up to 10	no charge
from 30 to 60	$0.67	from 10 to 20	$0.15
from 60 to 120	$0.77	from 20 to 30	$0.17
from 120 to 240	$1.00	from 30 to 60	$0.40
from 240 to 420	$1.17	from 60 to 120	$0.47
from 420 to 660	$1.40	from 120 to 240	$0.63
from 660 to 960	$1.63	from 240 to 420	$0.73
over 960	$1.87	from 420 to 660	$0.83
		from 660 to 960	$0.93
		over 960	$1.07

TABLE 3.3 Water Rates in the Federal District in 1992.
All values are in pesos.
Sources of information: Departamento del Distrito Federal, 1992

Water prices increase according to the bimonthly consumption of the users. The industrial and commercial consumers require a greater volume of water than domestic users, and so are entitled to a higher rate. The following section attempts to establish which activities require the greater amounts of water, in order to determine the water requirements for a number of urban activities.

3.3 Consumption patterns of water in the industrial, commercial, and residential sector

Thompson stresses that technology is an important factor influencing water demand, as technological inventions have increased the demands on water supplies during the 20th century. The development of indoor plumbing dramatically increased per capita water use. Similarly, untold manufacturing and industrial processes require water as an integral component of production (Thompson, 126-7).

Falkenmark and Lindh identify three phases of a culture's development involved with water exploitation:

1. Pre-industrialized societies, where water is abundant and the human influence on it is characterized by relatively small variation in the flow systems.
2. In a second phase of development, dams are built either to generate hydroelectric power, or for irrigation, or both. The control of water allows its transfer to dry regions and a more efficient regional use of water resources.
3. In the third phase, the maximum control of a stream flow is reached and it is possible to mobilize water to satisfy demands. This stage involves high costs for water management and resources development.

Water plays a meaningful role in each one of the stages of the socio-economic development. Societies rely on water supply for both industrial production, and for basic human needs.

Shiklomanov estimated the dynamics of water use in the world by human activity as follows:

Water users	*1900*	*1960*	*1980*	*1990*	*2000*
Agriculture					
Withdrawal	525	1550	2290	2680	3250
Consumption	409	1180	11730	2050	2500
Industry					
Withdrawal	37.2	330	710	973	1280
Consumption	3.5	24.9	61.9	88.5	117
Municipal supply					
Withdrawal	16.1	82	200	300	441
Consumption	4	20.3	41.1	52.4	64.5
Reservoirs					
Withdrawal	0.3	23	120	170	220
Consumption	0.3	23	120	170	220
Total (rounded off)					
Withdrawal	579	1990	3320	4130	5190
Consumption	417	1250	1950	2360	2900

Units are km^3 per year.
TABLE 3.4 World water use by human activity.
Source: Shiklomanov, 1993.

Water demand increases as populations grow, and it is necessary to increase food production and manufactured goods in order to supply human needs. Table 3.5 shows the water use for a number of industrial and commercial activities in the United States per unit of production.

Industrial activity however, is by far the only economic activity that requires water as a main resource. Municipal establishments (commerce and services) play a significant role in the economic vigour of societies. Table 3.6 provides average and peak water use for municipal establishments in the U.S. for 1980.

Industry	Parameters of water use	Units of production	Gross water used	Intake	Consumption	Discharge	*Percentage of gross water used for* Non-contact cooling	Process and related	Sanitary and misc.
Meat-packing	Liters per tonne carcass weight	l/tonne	30,000	18,100	330	17,700	42	46	12
Poultry dressing	Liters per tonne ready-to-cook weight	l/tonne	30,800	27,300	1,240	26,100	12	77	12
Dairy products	Liters per tonne milk processed	l/tonne	7.06	4,320	260	4,020	53	27	19
Canned fruits and vegetables	Liter per tonne vegetables canned	l/tonne	82,200	39,200	3,550	35,700	19	67	13
Frozen fuits and vegetables	Liters per tonne vegetables frozen	l/tonne	93,900	58,800	1,250	57,600	19	72	8
Malt beverages	Liters per liter-beer and malt liquor	l/l	49	14	3	11	72	13	15
Pulp and paper mills	Liters per tonne-paper	l/tonne	543,000	158,000	4,920	151,000	18	80	1
Paper converting	Liters per tonne-paper converted	l/tonne	27,500	16,100	1,140	15,000	18	77	5
Synthetic rubber	Liters per tonne synthetic rubber	l/tonne	462,000	55,100	11,700	43,300	83	17	<0.05
Hydraulic cement	Liters per tonne cement	l/tonne	5,660	3,470	609	2860	82	17	1
Steel	Liters per tonne steel net tones	l/tonne	261,000	159,000	5,840	154,000	56	43	1
Iron and steel foundries	Liters per tonne ferrous castings	l/tonne	51,800	12,600	1,090	11,500	34	58	8
Primary cooper	Liters per tonne copper	l/tonne	442,000	142,000	34,200	109,000	52	46	2
Primary aluminium	Liters per tonne aluminium	l/tonne	410,000	99,700	1,590	98,100	72	26	2
Automobiles	Liters per automobiles	l/automobile	138,000	43,400	2,460	40,900	28	69	3

TABLE 3.5 Water use in United States for a selection of industrial and commercial activities
Sources: K.L. Kollar and P. MacAuley, 1980, as cited in *Water in Crisis* (405-6).

Type	*Unit*	*Average use*	*Peak use*
Hotels	**Liter/day/square meter**	**10.4**	**17.6**
Motels	**Liter/day/square meter**	**9.1**	**63.1**
Barber shops	**Liter/day/barber chair**	**207**	**1,470**
Beauty shops	**Liter/day/station**	**1,020**	**4,050**
Restaurants	**Liter/day/seat**	**91.6**	**632**
Night clubs	Liter/day/person served	5	5
Hospitals	**Liter/day/bed**	**1,310**	**3,450**
Nursing homes	**Liter/day/bed**	**503**	**1,600**
Medical offices	**Liter/day/square meter**	**25.2**	**202**
Laundry	**Liter/day/square meter**	**10.3**	**63.9**
Laundromats	**Liter/day/square meter**	**88.4**	**265**
Retail space	Liter/day/sales square meter	4.3	11
Elementary schools	Liter/day/student	20.4	186
High schools	Liter/day/student	25.1	458
Bus-rail depot	Liter/day/square meter	136	1,020
Car washes	Liter/day/inside square meter	194.7	1,280
Churches	Liter/day/member	0.5	17.8
Golf-swim clubs	**Liter/day/member**	**503**	**503**
Residential colleges	Liter/day/student	401	946
New office buildings	Liter/day/square meter	5.8	14.4
Theaters	Liter/day/seat	12.6	12.6
Service stations	Liter/day/inside square meter	10.2	1,280
Apartments	**Liter/day/occupied unit**	**821**	**1,640**
Fast food restaurants	**Liter/day/establishment**	**6,780**	**20,300**

TABLE 3.6 Use of water in selected municipal establishments, US, 1980.
Source: J.J. Boland as cited in Water in Crisis (411)

The commercial activities which consume the most water are highlighted in bold characters. Included in this diverse group are industries such as canneries, public services, including schools and hospitals, and businesses such as restaurants, hotels, motels, and laundries which all require to heat water to accomplish their processes.

Specific data for Mexico City's water consumption by activity is not available[2]. However, table 3.7 shows the minimum requirements for water provision in Mexico City.

Typology	Sub-genre	Minimum provision of water
I. Residential		
	Single family	150 l/person/day
II. Services		
Offices	Any kind	20 l/m2/day
Commerce	Commercial retails	6 l/m2/day
	Public markets	100 l/stand/day
	Public baths	300 l/person/showerhead/day
	Laundromats	40 l/kg of dry cloth
Health		
	Hospitals, clinics and health centres	800 l/bed/day
	Nursing homes and asylums	300 l/guest/day
Education and culture		
	Elementary education	20 l/student/turn
	High schools and universities	25 l/student/turn
	Temporal exhibitions	10 l/person/day
Entertainment		
	Meals and beverages	12 l/meal
	Recreation	6 l/seat/day
	Circus and shows	10 l/person/day
	Provision for animals	25 l/animal/day
	Outdoor sports with change rooms and showers	150 l/person/day
	Stadiums	10 l/seat/day

Continue...

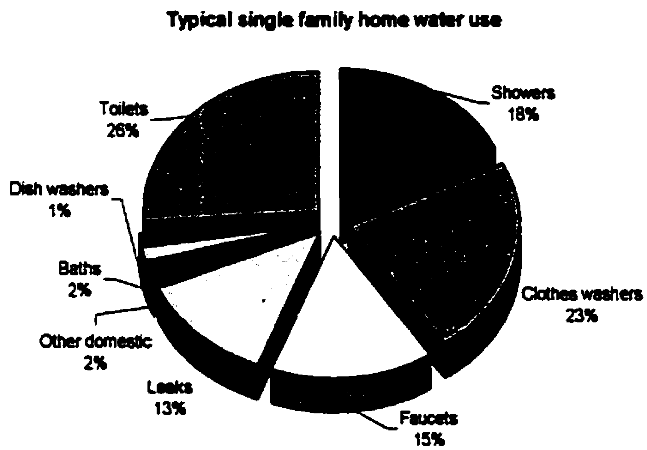
[2] The National Committee of Water is in the stage of developing a database.

Accomodation		
	Hotels, motels and guest houses	300 l/guest/day
Security		
	Prisons	150 l/person/day
	Barracks	150 l/person/day
Communications and transports		
	Transport stations	10 l/passenger/day
	Parking lots	2 l/m2/day
III. Industry		
	Industry where manipulation of materials and substances cause evidently uncleanliness	100 l/worker/day
	Other industries	30 l/worker/day
IV. Open areas		
	Parks and gardens	5 l/m2/day

Table 3.7 Minimum provision for water for Mexico City
Source: Building Regulation Code for the Federal District, 1989

The majority of establishments shown in table 3.6 have similar requirements in Mexico and presumably have resembling water consumption patterns. For example, water consumption in elementary and high schools is the same. Hospitals, nursing homes, and domestic consumption is about 20% higher in table 3.6 than in table 3.7, but one must keep in mind that data in table 3.7 are only the ***minimum*** provision of water that should be allocated.

In the domestic sector, the use of water is mostly associated with personal hygiene and washing. Figure 3.4 presents the use of water for a typical single American family[3]. This consumption pattern seems to be similar to that of urban, upper-class Mexicans, who are considered to be the second greatest potential target for solar water heaters in this study.



Activity	*litres per capita per day*
Showers	**49.97**
Clothes washers	**63.59**
Faucets	**43.15**
Leaks	35.58
Other domestic	6.06
Baths	**4.92**
Dish washers	**3.79**
Toilets	73.06
Total	*280.11*

Figure 3.4 Typical Single Family Home Water Use
Source: Water Wiser, American Water Works Association, 1998

Activities such as showering, washing clothes and dishes, bathing, shaving, and hand washing usually require hot water.

The World Health Organization recommends the provision of at least 20 liters of hot water for bathing (Morse, 26). However, the amount of hot water that should be

[3] Water consumption for a single family home without conservation measures. These numbers could be reduced significantly with efficient plumbing and if water saving devices, like high -pressure showers and 6 litres flush toilets are installed.

supplied for domestic use varies according to regional climate and personal preferences. For example, Enalter, a Brazilian manufacturer and dealer of solar water heaters estimates hot water requirements for residential use (litres per person per day) to be as follows: showering, 80 litres; faucets, 18 litres; clothes washing, 15 litres; dish washing, 8 litres; others 14 litres; total: 135 litres. The amount of water required for showering is higher than estimates for the U.S. and Mexico. According to Valdéz and Martínez[4], the amount of hot water used for showering in Mexico City is approximately 30 litres per person per day. Further provision of hot water for household uses could be estimated at 20-30 litres.

3.4 Conclusions

The organization and realization of a water supply, and the cost in terms of energy and money, of providing water for large urban settlements, has been analyzed in section 2.1.1 and 2.1.2. For both industrialized societies and urban settlements, water and energy availability involve the linking of the two resources into a complex system. Water is used in the production of energy in the form of electricity, or raw fuels and, at the same time, those fuels are used to purify, transport, and distribute water through municipal networks. However, this is only one step in the water cycle. Domestic, commercial, and industrial users, require, at a certain stage of their daily activities, to use hot water, which

[4] Eng. Alberto Valdéz Palacios and Eng. Rodolfo Martínez Strevel are professors at the National Autonomous University of Mexico.

once again represents an investment of energy that is mainly provided by burning fossil fuels. Nevertheless, emissions associated with combustion processes have hazardous effects on human health. As stated in chapter one, the industrial and the residential sectors, consume about 75% of the available energy in Mexico. This chapter shows how hotels, motels, hospitals, restaurants, laundromats, bottle cleaning and can packing plants for the soda industry, among others, need to be provided with large amounts of water and energy. This fact represents an opportunity to introduce solar water heaters as a strategy to reduce the use of fossil fuels to heat water in the MCMA, thus decreasing polluting emissions to the atmosphere.

Serageldin points that "alternative and renewable energy sources have a potentially crucial role to play in developing countries and in the business of sustainable cities." He also suggests that if solar technologies were first introduced for low-load domestic applications, businesspeople would eventually endorse to solar technologies as they become more and more convinced of the cost-effectiveness of solar power (Serageldin, 11). However, the position of this study is that small and medium-size businesses are more likely to be convinced to switch to solar facilities. The reason is that they are more stressed by the cost of fuels and new environmental policies that, trying to cope with pollution, impose higher and higher standards for equipment performance[5], therefore, investment in this kind of equipment could represent important savings in the future.

The next chapter of this thesis looks in detail at the most common systems and fuels used to heat water for small industries, public services, commerce, and dwellings. It also presents a case study of a solar system operating in the MCMA that demonstrates the amount of potential savings from the use of solar water heaters.

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[5] See chapter 4, section 4.2.1 and table 4.1

Chapter 4: Alternative to the use of fossil fuels and traditional methods for heating water

4.1 Introduction

The analysis of water and energy consumption patterns for the MCMA seen in chapter three emphasize that, the necessity of providing water and energy in large quantities for a portion of the industrial sector and municipal establishments, was a determining factor in their being considered potential users of solar thermal technology. This chapter presents the next step in the analysis of the possible benefits of using solar water heaters (SWH). It examines the ways in which traditional water heating systems work, and prices of the different fuels employed. It then reviews a case study of a solar water heating system installation actually operating in the MCMA, that provides over 75,000 litres of hot water per day.

4.2 Traditional water heater systems, efficiency, and costs of fuel

4.2.1 Boilers for commercial and industrial application

The amount of fuel used to heat water varies according to the size of the establishment, temperature and hot water volume requirements, and the type of system involved. The most widely employed liquid fossil fuels in the MCMA by the industrial and services sector, are diesel and fuel oil (chapter 2, table 2.3). Both have a high-energy content, and are easy to store in non-pressurized tanks, making them suitable to keep in the service yard of the business. Gaseous fuels employed are natural gas and liquefied petroleum gas (LPG).

Diesel fuels are mixtures of various hydrocarbons, and are produced by the distillation of mineral oil and/or by 'cracking' and hydrogenation of the residual products of the distillation process. Liquefied petroleum gas is predominantly propane and is produced from petroleum during the normal distillation process. Depending on the ambient temperature, it is stored in a liquefied state at pressures between 5.19 kg/cm^2 and 15.63 kg/cm^2 (511-1540 kPa). In this physical state it has an energy content slightly lower than that of liquid fuels (Wellington 576).

The most common devices used to heat water to high temperatures and for the production of steam are iron or steel boilers. Garcia-Borras provides a definition and classifies boilers as follows:

A boiler is basically a cast-iron or steel pressure vessel designed to transfer heat produced by combustion to a fluid. It is used to produce hot water, saturated steam (steam at its saturated temperature), or superheated steam (steam heated above the saturation temperature).

Non-electrical boilers, have six basic parts:

1. Burner, or nozzle, which is the heart of the boiler.
2. Combustion space, or firebox.
3. Convection section.

4. Stack.

5. Air fans.

6. Instrumentation and controls

Boilers can be classified in different ways according to the fuel they use:

1. Liquid fuels

2. Natural gas

3. Coal. These boilers are used when high steam production is required. They require large capital investments.

4. Other solid fuels: solid waste, bagasse, etc.

5. Combination of the preceding. Liquid and natural gas boilers are common (Garcia-Borras 7).

According to Garcia-Borras, boilers can also be classified into three general types by the way they are built:

Firetube boilers: In this type of boiler, hot gases flow inside tubes that are submerged in water within a shell. Design operating pressures are about 1,034 kPa (10.5 kg/cm^2) producing up to 13,154 kg of steam per hour. This type of boiler is the most popular and is used in small industrial plants. They require a low initial investment and have high rates of efficiency (80% or higher). They can meet wide and sudden load fluctuations with only slight pressure changes, because of the large volume of water stored in the shell, and they are ready to use after being delivered on site.

Watertube boilers: In these boilers, water flows through tubes that are surrounded by hot combustion gases in a shell. They are usually rated by pounds of steam per hour, and they range from about 2000 lb/hr to 10,000,000 lb/hr steam (917 kg/hr to 4,535,900 kg/hr). Because they are used for high-pressure steam, they require more instrumentation and more controls, but they are less effective than firetube boilers.

Electrical boilers: They are less efficient than fuel-fired boilers; however, they have no stack losses and no burner cleaning or adjustment (Garcia-Borras 9).

Inside boilers, the combustion process is regulated by the flows of air and fuel. The combustion obtained by the reaction between the exact proportions of fuel and oxygen to effect complete conversion to carbon dioxide, water vapor, and sulfur dioxide (if sulfur is present) is called perfect combustion, or stoichiometric combustion. Excess air does not help fuel combustion; when there is no more fuel to burn it merely cools down the hot gases. Oxygen (O_2) for combustion usually comes from air, which contains approximately 21% O2 and 79% nitrogen (N_2) (Garcia-Borras 17-19).

The amount of heat obtained from burning a fuel depends on the fuel and its composition. The two heating values provided for fuels are: gross and net heating value. The difference between these values is related to the heat from vaporization of water. More usable heat is released when water is condensed than when it escapes as vapor. When water is removed as a vapor, the heat of vaporization is lost. If water is allowed to cool to a liquid before it leaves the stack, the heat of vaporization is released.

In general, fuels are specified and sold by gross heating value, but most commercial applications realize only the net heating value because the combustion gases are vented at a temperature above which condensation would occur.

Comparative analysis of typical fuels

		Analysis, % by weight			*Heating Value Kcal/kg**	
Fuel	**Carbon**	**Hydrogen**	**Sulfur**	**Ash**	**Gross**	**Net**
Natural gas	75	25	-	-	13,250	11,940
Propane	82	18	-	-	11,980	11,030
Butane	83	17	-	-	11,800	10,900
Naphtha	85	15	0.03	-	11,556	10,640
Kerosene	86	13.7	0.07	-	11,000	10,310
Fuel oil	86	13.2	0.3	-	19,098	17,982
Coal, bituminous	80	5.5	1.5	5	7,830	7,550
Coke	85	0.5	1	12	6,889	6,950
Charcoal	-	-	-	-	8,000	**
Wood	-	-	-	-	4,800	**

*To obtain Btu/lb multiply by 1.8

**Water content varies widely.

Note: Natural gas, propane and butane have higher hydrogen contents per unit of weight than liquid or solid fuels, which results in higher heating values. But when equeal volumes of gas and oil are burned, the fuel oil gives up more heat because fuel oils contains more hydro-carbons per unit volume (higher specific gravity) than the gas.

Table 4.1

Source: Adapted from Garcia-Borras.

According to the Ministry of Energy, in 1995 the industrial sector consumed 1,384.66 petajoules of energy. The percentage of energy provided by fuel was: natural gas 48.23%, electricity 16.32%; fuel oil 16.79%, diesel 5.05%, LPG 1.31%, coke 6.05%, and other fuels 6.23%.

There are two Mexican Official Regulations (Norma Oficial Mexicana NOM-002-ENER-1995 and NOM-012-ENER-1996) that establish the minimum thermal efficiency levels for firetube and watertube boilers, as shown in table 4.2. The Regulation applies for boilers with the following characteristics:

	NOM-012-ENER-1996	NOM-005-ENER-1995
Capacity	From 7.4 to 100 kW	From 100 to 8 000 kW
Pressure	Up to 1 MPa	Up to 1 MPa
Temperature	Saturation	Saturation

Minimum efficiency for boilers, based on the maximum heating power.

	Thermal load kW	Efficiency (%)*	Combustible
Firetube boilers	7.4-100	76	Natural gas o L.PG
	7.4-100	80	Fuel oil, gasoil, diesel
	100-200	76	Natural gas o L.PG
	100-200	80	Fuel oil, gasoil, diesel
	200-8000	76	Natural gas o L.PG
	200-8000	80	Fuel oil, gasoil, diesel
Watertube boilers	7.4-100	76	Natural gas o L.PG
	7.4-100	80	Fuel oil, gasoil, diesel
	100-200	74	Natural gas o L.PG
	100-200	78	Fuel oil, gasoil, diesel
	200-8000	76	Natural gas o L.PG
	200-8000	80	Fuel oil, gasoil, diesel

Table 4.2
***Relation between the heat absorbed by the water and the output heat provided by the fuel. Efficiency was obtained using the indirect method.**
Source: Norma Oficial Mexicana NOM-002-ENER-1995

With the application of the Regulation, and considering the production of 170 equipment per year, there is an estimated average of 10% savings in the consumption of natural gas (23 millions cubic meters). Emissions to the environment are also expected to be reduced (53,650 ton CO_2 and 17 ton of CO) (CONAE).

4.2.2 Heaters for domestic and commercial application

The Mexican Official Regulation (Norma Oficial Mexicana NOM-003-ENER-1995) establishes the minimum thermal efficiency levels for domestic and commercial heaters that use natural gas or LPG as their combustion fuel (table 4.3). The Regulation defines a domestic heater as one with a thermal load of under 35 kW. Commercial heaters have a thermal load of between 35 and 80 kW. Both types are intended to produce only liquid hot water.

Both domestic and commercial heaters consist of:

1.Combustion space

2. A heat exchanger

3. A burner

4. A pilot light

They may be controlled by a thermostat (automatic control of temperature), a valve (semiautomatic control), or by pressure control. There are four types of heaters:

Storage heaters. They consist on a cylindrical deposit to storage water. Water intake and output are located at the top of the boiler. Output gases from combustion pass through a coil which retains them in the system and thus obtains a more efficient use of heat produced in the burner.

Fast recovery heaters. They consist of a combustion chamber and a coil through which the water circulates in order to be heated. They operate by temperature variation in the water; when their thermostatic controls detect a drop in water temperature, the boiler allows a flow of gas to pass to the burner.

By-pass heaters. The burner turns on and off automatically when it detects a difference in pressure in the burning chamber, as a result of water runs through the system.

Electrical heaters. Operation of this kind of heater is similar that of storage heaters. The main differences are that the heating element is an electric coil, and temperature is regulated by an electric thermostat (Revista del Consumidor, XXII).

Minimum efficiency for heaters, based on the minimum heating power

Type of heater		Thermal load kW
	Storage (from 20 l to 360 l) Automatic and semiautomatic	6.0-35.0
	Fast recovery	6.0-35.0
	By-pass Automatic and semiautomatic	6.0-35.0
Commercial	Storage	35.0-80.0
	Fast recovery	35.0-80.0
	By-pass	35.0-80.0

Year	Thermal Efficiency %	
	Domestic	Commercial
1995	70,0	75,0
1996	72,0*	77,0*
1997 and beyond	74,0*	79,0*

Table 4.3
*Value under revision
Source: Norma Oficial Mexicana NOM-003-ENER-1995

In February 1999, the Consumer's Magazine of Mexico (Revista del Consumidor) published an evaluation of water heaters. The study analyzes 52 different models and assigns a global quality rating of up to 100 points. It includes prices for all the analyzed models, a list of physical features to consider for each category of heaters, and general recommendations for installation and purchase. Analyzed models include 32 storage heaters, 12 fast recovery heaters, 2 electric heaters and 6 pass by heaters. Heaters were from 14 different companies (48 national and 4 imported) and were subject of the following tests:

1. Information provided to the consumer
2. Warranty evaluation
3. Finishing verification
4. Volumetric capacity test (storage and electric heaters)
5. Heating capacity test (pass by and fast recovery heaters)
6. Thermal efficiency test
7. Recovery time test (storage and electric heaters)
8. Combustion test (do not apply for electric heaters)
9. Wind resistance of the burning flame test
10. Pollutant emissions test (do not apply for electric heaters)

Type of heater	*Analyzed models*	*Capacity*	*Price range (Mexican pesos)*
Fast recovery	3	5-7 l/min	1,376-2,588
	6	9 -15 l/min	2,230-6,900
	3	18-23 l/min	6,580-11,587
Pass by	6	4-9 l/min	1,265-2,999
Electric	2	22-38 l	1,083-1,430
Storage	12	38-49 l	484-3,184
	5	58-62 l	1,249-3,540
	5	72-76 l	1,431-3,783
	4	96-106 l	1,306-4,425
	5	114-132 l	1,502-4,716
	1	200 l	3,160

Table 4.4 Prices of water heaters in Mexico City
Source: Revista del Consumidor
Note: Prices for December 1998. One US dollar = 10 pesos, approximately.

The study reveals that 19 of the heaters from all categories (36%) acquired a global mark of 100 points, meaning that they ranked "excellent" for all tests. Nineteen heaters (electrical models were not included) ranked from "deficient" to "good" in the pollutant emissions test, and 20 heaters had a "regular" to "good" performance.

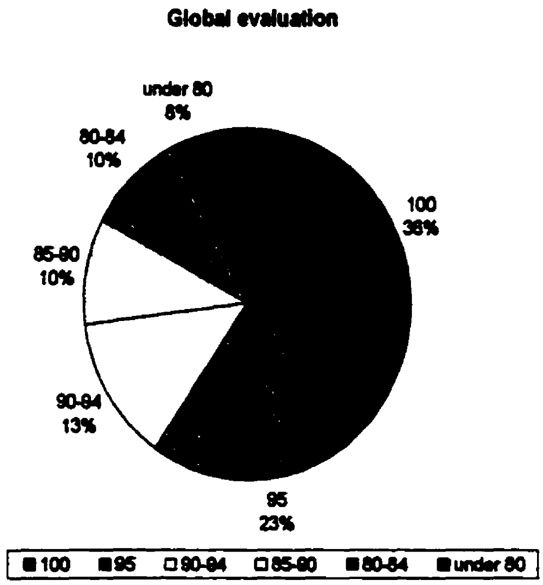

Figure 4.1 Global evaluation of domestic water heaters
Source: Revista del Consumidor

According to Sheinbaum, the residential sector is responsible for the 20% of the final energy consumption in Mexico, which had an average annual growth of 2.8% between 1970 and 1990. However, the demand for LPG rose from 15% in 1970, to 38% in 1990 (Sheinbaum, 123).

The final use of energy, for the residential urban sector was, in 1990:

Final use	GJ per capita	%
Cooking	3.20	44
Water heating	2.75	38
Lighting	0.35	5
Appliances	1	13

Table 4.5 Residential use of energy in Mexico
Source: Sheinbaum, 1996

After cooking, water heating is the most important final use of energy in the residential sector. Sales of water heaters across the country rose from 400 thousand units in 1980 to more than 600 thousands units in 1990, and it is estimated that only 10% of these sales took place in the rural sector (Sheinbaum, 122).

In 1990 there were a total of 11.9 million urban dwellings in Mexico consuming an average of 3.2 kg per capita per day of LPG (a total of 14.2 GJ per dwelling). Considering that the MCMA constitutes about the 20% of the total population of the country, it is possible to deduce that there is a daily consumption of about 57,600 tones per day in the city and that about 22,000 tones are destined for water heating.

4.2.3 How the energy policy in Mexico influences the use of fossil fuels

In countries that struggled with oil shortages in past decades or that heavily rely on oil imports to satisfy internal energy demands, the use of solar energy has had large promotion among both the domestic market, and the general industry, and research and development has been encouraged and given economic support. In some cases, there have been governmental incentives such as tax-credits to enforce the implementation of solar devices. In her essay "Mexico's Progress in Planning and Development of New Energy Sources" Vargas describes Mexico's policy regarding the use of renewable energy:

> By the mid-1970s Mexico's energy situation was favorable because of the new hydrocarbon discoveries. Although the abundance of hydrocarbons clouded the foresight of the experts about the importance of alternative energy resources, the first serious energy-programming attempt in 1980 established among its objectives primary energy-sources diversification, which included the exploitation and use of alternative energy forms. Although the potential importance of solar energy was noted, the program stressed that the only non-conventional source that could offer any significant contribution was geothermal power, which it was hoped would be 0.4 percent of the energy produced in the country in 1990. The 1984 energy program confirmed that in the long term solar energy would offer the most opportunities because recovery investment in research and

development was almost assured as a result of the resource's potential and technological flexibility... The translation of these ideas into a concrete energy program, though, was somewhat less than satisfactory. First, high priority was not ascribed to alternative energy sources, and how to carry out a diversification strategy was not defined. Second, the link between these and other energy policy objectives was not made explicit, nor was their relationship to macroeconomic policy clarified. The energy program included the use of alternative sources in power projects designed to satisfy the energy requirement of isolated and dispersed rural communities where the expansion and integration of the national electricity grid would have been very costly and practically impossible. These sources were considered then as means of satisfying localized demands and not as a part of a program for conventional sources designed to satisfy massive demand. This order of priorities was reflected in the limited economic resources made available for the development of the alternative sources as opposed to the volumes of investment in other relatively recent energy developments such as nuclear power. Most of the technology on alternative sources in Mexico is at the research or pilot-plant stage. Any advancement is confined basically to teaching and research institutions, certain public organizations, and to a lesser extent, professional associations. The scope of the institutions working on the development of these sources is limited by economic factors; thus, despite the progress made in pure and even applied research, the diffusion of conversion equipment has been marginal. This limit has meant that knowledge of the possibilities, range, and function of this equipment has been restricted to very specialized circles. It is obvious there is a lack of communication between scientific and technological research organizations and the industrial sector. Industry firms utilizing these energy sources are practically nonexistent (Vargas, 168-69).

Artículo 27 (Article 27) of the Mexican Political Constitution grants the state property rights over land and waters within its territory as well as the right to impose on private property the method of exploitation that the state considers most beneficial. The country's two largest energy companies, Petróleos Mexicanos (Mexican Petroleum Company, PEMEX), and the Comisión Federal de Electricidad (Federal Electricity Commission, CFE), whose activities together represent almost all of the country's primary and secondary commercial energy production, are state-owned. PEMEX has a monopoly over exploration, exploitation, production, refining, and distribution of crude oil and natural gas and is, also by constitutional decree, the only producer of primary petrochemicals. CFE has a monopoly over generation, transformation, transmission, and distribution of electric power. Between the late 1970s and early 1980s, oil became a fundamental factor in the new Mexican development model, and taxes on hydrocarbon exports became one of the most important sources of income for the state. PEMEX rewarded the state not only with growing level of tributary resources and high-income potential, but also with the image of great international solvency. Additionally, the energy sector contributed to the industrialization and accelerated growth of the gross domestic product by granting subsidies to most of the companies selling their output locally (Gutiérrez, 2-10). Subsidies in the form of preferential prices for energy consumed are intended to encourage the development of different productive areas (Gutiérrez, 28). The effectiveness of this policy has been largely questioned and a number of studies have been made which demonstrate that it has a counterproductive effect over the Mexican economy. Waste of energy resources is strongly associated with this method of energy handling. Nevertheless it is still considered to be a protective measure for low-income groups that would be immediately affected by a sudden increase in fuel prices. Table 4.4 shows the prices of combustible fossil fuels for 1998 and 1999.

Combustible prices for 1998 and 1999

	LPG	Gasoline Pemex Premium	Pemex Diesel	Diesel Without sulfur	Industrial Gas oil	Fuel oil
1998	3.28	4.66	3.35	3.27	1.09	0.79
Jan	3.13	3.73	2.69	2.61	1.19	0.77
Jul	3.24	3.91	2.80	2.72	1.04	0.75
Dec	3.28	4.66	3.35	3.27	1.09	0.79
annual increment	4.79%	24.93%	24.54%	25.29%	-8.40%	2.60%
1999	3.41	5.06	3.81	3.73	1.50	1.09
Jan	3.31	4.70	3.56	3.48	0.91	0.71
Jul	3.37	5.00	3.77	3.69	1.40	0.99
Aug	3.41	5.06	3.81	3.73	1.50	1.09
increment between Jan/99 and Aug/99	3.02%	7.66%	7.02%	7.18%	64.84%	53.52%
*	8.95%	35.66%	41.64%	42.91%	26.05%	41.56%

Table 4.6 Combustible prices in pesos per litre.
*Increment between Jan/98 and Aug/99
Source: PEMEX

During the 1990s, the issue of the possible privatization of PEMEX has raised the level of general concern about the future of the subsidizing policy. Certain petrochemical industries have already been sold to private investors. Furthermore, during 1995, the possibility of allowing foreign enterprises to build and operate ducts, installations, and equipment for the transport, storage and distribution of gas, was part of a proposal to change the Statutory Law of Article 27 (Ley Reglamentaria del Artículo 27)(Gershenson). PEMEX is not the only government-owned company which has been subject of privatization projects: during 1999, proposals emerged for CFE to be sold. If the state decides to redistribute the rights to the country's energy management and exploitation of resources, prices are expected to reach international standards and living, transportation, and production costs may increase dramatically.

Regardless of whether these changes will be carried out in the near future, an increase in cost of fuels is inevitable. The strong dependence on oil profits has had the effect of making the Mexican economy vulnerable to economic crises. Mexico was seriously affected during 1998 as a consequence of the devaluation of oil price in the international market, and the population immediately suffered the negative effects of this. For instance, the price of diesel and fuel oil rose above 40% since January 1998. Only LPG keeps a price gain below 10%.

If solar energy technologies were installed to preheat water for industrial processes, there is a possibility to save at least 15% of fuel. Given the enormous amount of fuel involved in industrial processes, and the high consumption by commerce and domestic users, reduction in the use of fossil fuels through the use of solar devices could also represent significant savings in terms of money and airborne pollution.

The next section of this study explains what a solar water heater is and how it works, both as an independent system which supplies hot water for human use, and as a combined system that serves to preheat water when higher temperatures are required.

4.3 Solar Water Heaters as an alternative to traditional methods and fuels

Mexico's geographic location is conducive to extensive use of solar technologies. Located within the insulation belt, the average global daily radiation for the MCMA is between a minimum of 13.5 MJ/m^2 and 20.7 MJ/m^2 (Almanza, 11-23). The convenience of using solar energy in Mexico has been discussed by a number of scholars and institutions throughout the country. Vargas stresses that, compared to other sources, solar energy has received most of the financial resources assigned for research. Thus, considerable technological progress has been made in this field, and some of the equipment and mechanisms used have become competitive internationally (Vargas, 180). According to Vargas, technology for developing flat solar collectors is the one which has developed a commercial market, basically because of the high level of design, construction and standardization. Some of the components for photothermal systems (thermal active technologies) were imported until the drastic changes in the parity of the Mexican peso with the U.S. dollar obliged almost complete suspension of foreign purchases. These imports were part of different scientific collaboration agreements between the Mexican government and France, Germany, Italy, the United States, and Japan since 1973. However, local techniques and resources have prevailed, and in certain cases, product results have come from the adaptation of foreign technology to local needs, a feat achieved more by maintaining and dismantling equipment than by any real transference of know-how (Vargas, 181).

Solar thermal technologies, both passive and active, have been constantly evolving and nowadays there are multiple fields of application:

Passive technologies for heating, cooling and lighting are used in architectural design.

Active technologies are employed to convert solar radiation into heat that is then transferred to a fluid. Heat is then used for a number of purposes such as space or water heating, drying grains, water distillation or air conditioning. Solar thermal collectors can be classified into three categories:

Flat-plate solar collectors: Provide water heating up to 65°C through metallic and non-metallic absorbers.

Intermediate temperature collectors: Require the concentration of solar radiation (e.g. parabolic-trough collectors) to produce water temperatures of between 100-300°C.

High temperature collectors: Can achieve temperatures above 500°C by tracking the sun path and are used to produce electricity. Three major designs have been developed: 1) the parabolic-trough system, which concentrates solar energy onto a receiver pipe located along the focal line of a trough collector; 2) the central-receiver system, which uses sun-tracking mirrors called heliostats to reflect solar energy onto a receiver/heat exchanger located on top of a tower; and 3) the parabolic-dish system, which uses a tracking dish reflector to concentrate sunlight onto either a receiver/engine or a receiver/heat exchanger mounted at the focal point of the dish (De Laquil 214).

Solar Water Heaters (SWH) are flat-plate collectors that offer an alternative for supplying hot water for domestic, commercial and industrial use. In the U.S.A., solar thermal energy use for water heating in residential and commercial sectors is expected to expand through 2010 (Kreith 236).

4.3.1 How Solar Water Heaters work

The typical flat-plate collector panel is an insulated weathertight box containing a dark solar absorber plate under one or more transparent covers. The dark absorber soaks up heat from sunlight that passes through the cover and then passes the heat to a heat-transfer fluid flowing past or through the absorber. This fluid (water, a non-freezing liquid, or air) delivers its heat directly or indirectly to water stored in an insulated tank (McPherson 12). The average dimension of SWH is about 1.8-2.1 square meters, and the storage tank capacity for domestic purposes is usually 150-200 litres.

Solar Water Heater systems can be characterized as either direct or indirect, depending on the manner in which water is heated. In direct (open loop) systems, the fluid heated in the collector is plain water, which flows directly to supply demand. In indirect (closed loop) systems, the heat-transfer fluid is treated water, air, or some non-freezing liquid. The heat it picks up from the absorber plate is passed along to the house water through a heat exchanger, such as a coil inside the tank or wrapped around the storage tank shell under the insulation (McPherson 14).

Both, direct and indirect systems work either by thermosiphoning or with the aid of a pump:

Thermosiphoning. In this system water circulates by natural convection and gravity, rising and falling in response to solar heat. As long as the absorber keeps collecting heat, water warmed in the collector rises into a storage tank placed slightly above it, while cooler tank water runs down to take its place. Thermosiphoning units are simple, relatively inexpensive, and require little maintenance. In their simplest form they are not suited to freezing climates, because water remains in the collector at all times.[1] The storage tank must be located at least 60 cm above the collectors (McPherson 14).

Pumped. A direct pumped system is often used when more flexibility in system layout is needed. With forced circulation, the tank need not be located above or even near the collectors. A direct pumped system typically relies on "drain-down" for protection against freezing. The pump moves water through the collectors only when there is enough solar radiation to produce useful heat. When the pump shuts off – whether by automatic control or due to power failure—the collectors are drained by gravity flow (McPherson 15).

[1] However it is possible to install a small anti-freezing module that contains a fluid (e.g. glycol) that prevents freezing, or a valve to drain the collectors.

Thermosiphoning systems are the most economic choice for residential use (single family). Pumped systems are aimed to accommodate circulation of larger volumes of hot water, as in the case of multi-family residential units, commerce, industry, and pool heating.

Eventually, other devices such as thermostat controls and back-up systems may be added. Back-up systems could be a conventional gas (or diesel) system or an electric one. When back-up systems are used, the solar system serves more as a pre-heater rather than being the main heating system. Nevertheless it still provides considerable savings.

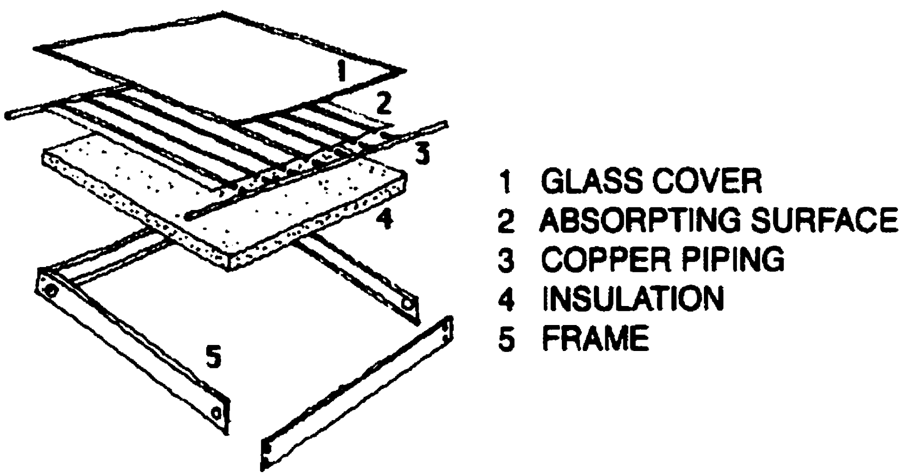

Figure 4.2 Components of a flat-plate collector

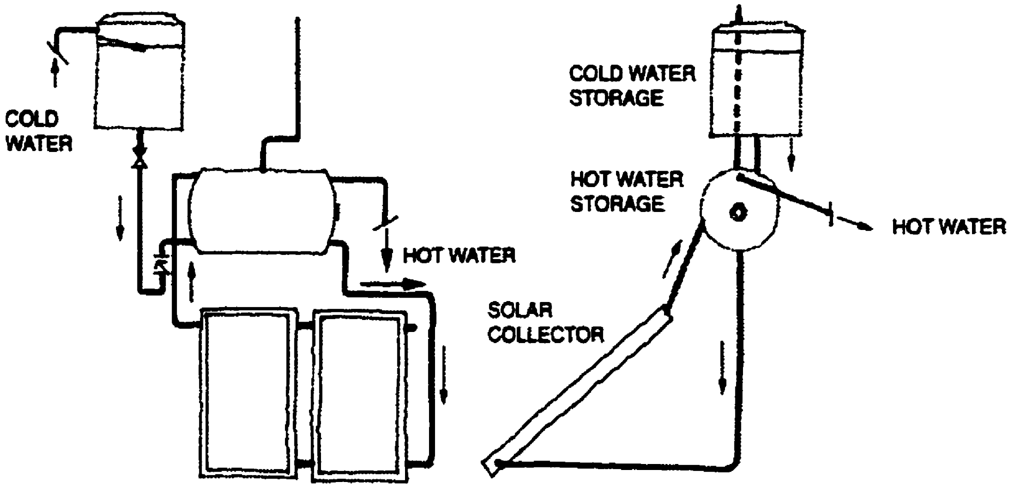

Figure 4.3 Thermosiphonig system

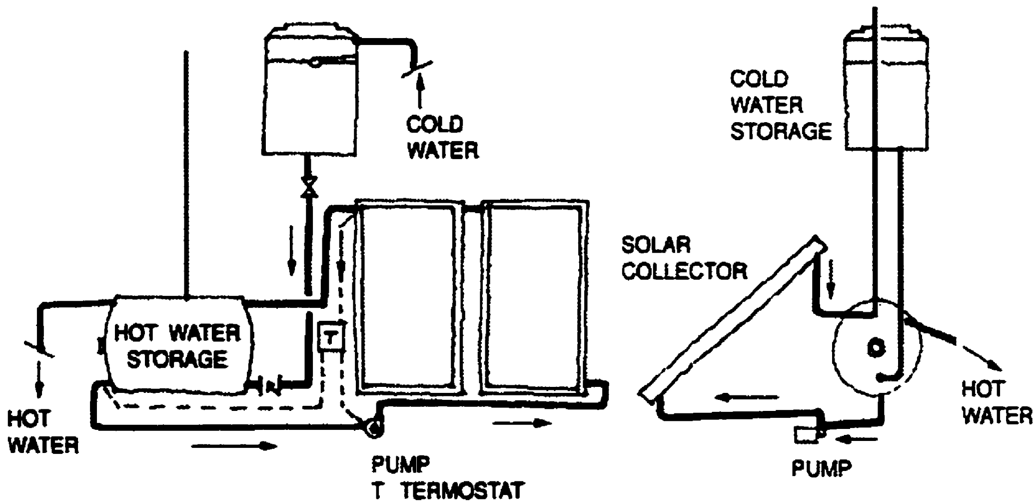

Figure 4.4 Pumped system

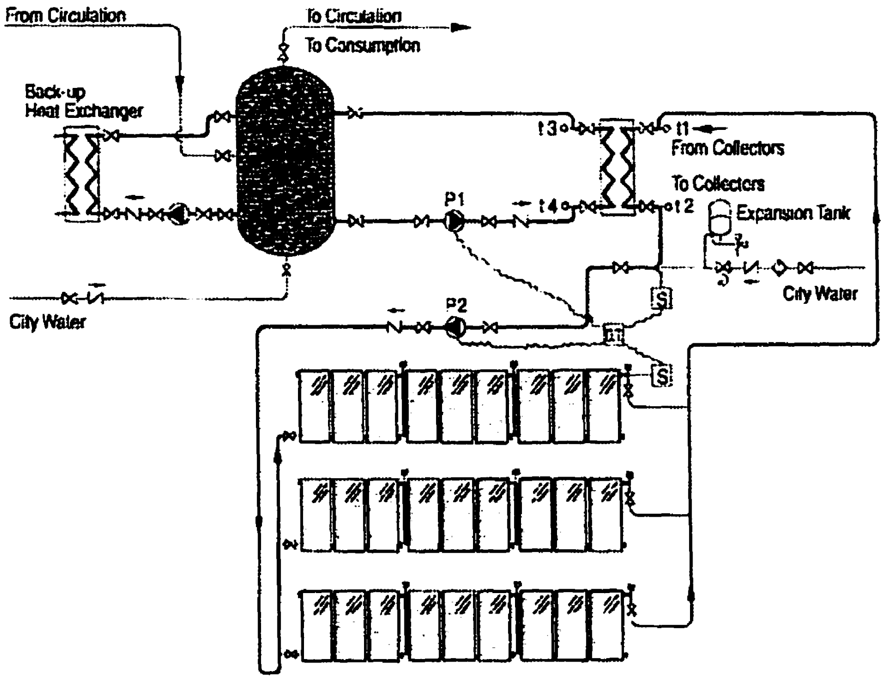

Figure 4.5 Array of solar water heaters

4.4 Case Study

The following is an example of a solar water heater system in actual operation in Mexico City. The system was installed during the hospital's major renovation during 1993, and has been working up to date. Data was collected on site, both through direct observation and interviews with the Maintenance Engineer in turn.

Project: **"20 de Noviembre" National Medical Center**

Contractors: Aquasol S.A. de C.V., Módulo Solar and Constructora ICA.

Place: Mexico City.

Year of construction: 1993

Project leaders: Jaime Sotomayor, Carlos Sotomayor and Octavio García.

Description of the project: 1000 square metres of collecting surface (aluminum plate and copper piping, and copper plate and piping collectors), modules of 1.9 sq.m., pumped system. The system delivers hot water for all purposes in the hospital, at rates of 50-60 cubic meters per day (Source: CONAE).

Hospital built surface	***m2***
Building A (Hospital Tower)	40,829
Building B (Extern consultation)	8,333
Building C (Administration)	1,210
Building D (Research and Labs)	10,230
Building E (Classrooms)	845
Building F (Medical Internship)	86
Building G (Parking)	222
Total	**61,755**

Table 4.7 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Hospital built surface.

Requirements of hot water/vapor

Central kitchen		6 cooking pots	150 l/pot	900 l
Floor kitchenettes		10 units		n.a
Sterilization and Equipment Center		vapor 118-130°C		n.a
Air conditioner				n.a
Showers	(3600 employees)			
	Morning shift	800-1000 showers*		120,000-150,000 l
	Afternoon shift	400 showers		60,000 l
	Evening shift	400 showers		60,000 l
	Nursing school	100 showers		5,000 l
	Interns	150 showers		22,500 l
	Patients	400 showers		60,000 l
	Total	2200 showers		330,000 l
No laundry				
Laboratories				n.a
Extern consultation (1000 patients/day)				n.a

*150 l of water per shower: 100 cold water + 50 hot water

Table 4.8 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Requirements of hot water.

Water storage (cisterns' capacity)	
Building A	388 m^3
Building B	120 m^3
Parking building	44.80 m^3
Nursing school	151.20 m^3
Total	704 m^3

*Water is taken from municipal pipelines

Table 4.9 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Water storage capacity.

Water discharge

Discharge cisterns' capacity	
Primary cistern	480 m^3
Secondary cistern	900 m^3
Subtotal	1380 m^3
Total (2 discharges per day)	2760 m^3

Table 4.10 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Discharge cisterns' capacity.

Hot water tanks

Solar Pre-heating system	*4*19,000 l = 76,000 l*
Average temperature	30°C
Pressure	5 kg/cm^3
Maximum temperature registered	65°C (May)
Reserves	4*20,000 l = 80,000 l
Total	156,000 l
% of heat losses due to distribution:	n.a.

Table 4.11 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Thermal storage tanks' capacity.

Backup equipment to meet hot water and vapor requirements

The system works as a solar plus backup system. Solar arrays were installed to provide pre-heated water to the existing boiler in order to reduce time and fuel for the vapor to be produced.

Watertube Boiler	13,608 kg/hr nominal capacity (750 vapor horse power pressure)
Vapor production	400 ton/hr
Fuel:	Diesel
Fuel consumption:	300 l/hr (90,000 l/month)*
Fuel storage tank capacity:	15,000 l
Fuel costs:	$339,300/month** ($US 33,930)

*A truck comes 6 times per month to refill the diesel tank

** Diesel price for July 1999

Table 4.12 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Characteristics of the backup system

Savings estimation due to solar system

Maintenance engineers calculate fuel savings of around 15-20% per month (16,875-22,500 litres of diesel), otherwise estimated as a monthly consumption of 112,500 litres. Economic savings are about $63,618-$84,825 pesos per month ($890,658 pesos annual average savings).

Cost of the solar system

The cost of the solar system was not available. However, an estimate is done based on the cost of similar solar water heaters (see appendix B).

Collecting surface	1000 sq. m.
Cost per square meter*	$853
Cost of storage tanks	$760,000
Subtotal	$1,613,000
Installation cost**	$483,900
Total	**$2,096,900**

* Price in pesos per square meter for a copper plate and piping collector, as for October 1999.
** Installation cost is about 30% of the total cost of the system.
Table 4.13 Case Study.
"20 de Noviembre" National Medical Center, Mexico City.
Estimated cost of the solar system.

If the solar collectors were to be installed today, the average annual savings per year ($890,658 pesos) could pay for the system in 2.35 years[2].

Benefits of the solar-powered system, other than fuel savings, have been observed by the maintenance team. The preheating of water considerably reduces the time for the vapor to be produced in the boiler (on clear days in spring/summer, the system provides water at temperatures up to 65°C). Furthermore, output hot water that is circulated towards the storage tank via the three-dimensional roof structure that shelters the hall of the building, prevents the accumulation of ice from an occasional hailstorm on the structure's glass cover, thus serving as an anti-freezing device.

The solar system does not generate air pollution, is silent (an important feature given the type of building), and requires minimal maintenance procedures, such as periodic cleaning of the glazing surfaces and inspection of flow rates and piping leaks.

[2] Calculation based on a simple payback analysis. See chapter 5, page 104, and appendix A.

4.5 Conclusions

The type of system used for water heating is an important element in determining the amount of energy and money expended on the heating of water. In the industrial sector, watertube and firetube boilers are common devices used when high temperatures are required for steam production. The average efficiency rating for boilers working with natural and LP gas is approximately 76%, and 80% for those working with fuel oil, gasoil and diesel. The combustion processes that take place inside these boilers leads to the production of heat, but also to the production of toxic gases such as sulfur dioxide and carbon dioxide. The amount of heat and polluting emissions obtained depends largely on the chemical composition of the fuel. Diesel is largely used as a combustible for industrial boilers; however, it contains sulfur which later combine with oxygen to produce sulfur dioxide. Natural gas is less polluting, nevertheless, each cubic metre of natural gas saved reduces carbon dioxide emission into the atmosphere by 2.33 kilogrames.

The subsidized system for oil products in Mexico encouraged for decades the use of fossil fuels for a great variety of purposes. In 1995, the industrial sector consumed a total of 328.345 petajoules (PJ) of energy. Fossil fuel consumption was 230.82 PJ (16.79%) of fuel oil, 69.41 PJ (5.05%) of diesel, and 18 PJ (1.31%) of LPG. Information for the specific use for that energy was not available for this study; however, it is likely that a large amount of this fuels was used for steam production[3].

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[3] Other uses could be transportation of materials from place to place, and power supply for motors and machines.

Estimated consumption for the MCMA in 1990 was 22,000 tones of LPG destined only for domestic water heating, which is the second use of this fuel in urban dwellings. Domestic water heaters perform at about 72% of efficiency and therefore, are slightly less effective than industrial boilers. Although LPG is less polluting than diesel or other liquid fossil fuels, it is a dangerous material to handle and require the installation of proper piping and storage tanks to avoid leaks and accidents. Small solar water heater systems (4-6 sq. m) could easily satisfy demands of hot water for domestic use. However, given the fact that LPG is also used for cooking, and that the system represents a major investment, households may not want to use this technology unless they are having serious problems with gas delivery. This tendency may change in the future if prices for LPG continue to rise and the cost of a solar device becomes competitive in the energy market.

However, for higher volumes of fuel consumption, solar water heaters are a reasonable option. The case study demonstrates that, although the initial investment is high, the installation of SWH for water preheating represents important savings in terms of time for the steam to be produced, and fuel for the operation of a boiler. After a certain period of time, the savings on fuel will pay for the cost of the system and net gain could be obtained. If solar devices were installed in mass scale in the MCMA, it would be possible to achieve a significant reduction of polluting emissions and therefore, a better quality of life for its inhabitants.

Chapter 5: Conclusions

The analysis of the environmental statistics available for Mexico City made it possible to identify the principal pollutants and their origins. It was also possible to relate the use of energy, especially the utilization of fossil fuels, with the generation of harmful emissions. Transport is the sector that requires the highest input of energy and consequently is the cause of most pollution in the Mexico City Metropolitan Area. Industry is the second largest consumer of energy, and represents 57.3% of sulfur dioxide and 24.5% of nitrogen oxides emissions in the MCMA. The domestic, commercial and public sector is the third highest user of energy in Mexico, and is the second source of carbon monoxide, while the service sector counts alone for 38.9% of hydrocarbon and 15.9% of sulfur dioxide emissions.

The efficient use of energy in transportation is out of the scope of this study, which focuses on the potential contribution of the industrial, commercial, public, and residential sectors through the reduction of the amount of fossil fuel that these sectors consume. Considering that the provision of water is a process that itself requires large amounts of energy, and that a variety of activities require hot water for their operation, one of the objectives of this thesis was then to determine the most demanding consumers of hot water in the MCMA. Water consumption patterns for a number of industrial, commercial, public and residential users were extrapolated from statistics in the United States as detailed information for the use of water by sector in Mexico is not yet available. Statistics show that hotels, motels, hospitals, restaurants, laundromats, bottle cleaning and can packing plants for the soda industry, among other consumers, need to be provided with both, water and energy in large quantities. Although one can assume that these businesses operate in a similar way in the U.S. than in Mexico, there are still significant differences, and therefore, development of a local database is essential to provide a more accurate picture of the water consumption in the city.

In Mexico, the equipment used to provide hot water for these activities is classified either as industrial boilers or domestic heaters. Industrial boilers use diesel, natural gas, LPG, fuel oil and gasoil as fuel. The average efficiency level for these boilers and heaters is about 76% for those that use natural gas or LPG, and about 80% for those using fuel oil, gasoil and diesel. These fuels are widely available in the city, and have benefited from subsidies that make them an affordable energy option. However, subsidies tend to expire, and burning of fuel oil and diesel contributes to the generation of sulfur dioxide, which is toxic even at low concentrations, and can cause cardiovascular distress. Other pollutants derived from the burning of these fuels are carbon dioxide and nitrogen dioxide, which can increase the risk of respiratory disease, especially in vulnerable groups such as children under five, pregnant women, and the elderly. Domestic heaters use mainly LPG, which is less polluting than other fossil fuels; however, CONAE stresses that in 180 air samples taken from Mexico City between February 1993 and May 1995, there were high concentrations of reactive hydrocarbons derived from LPG. These concentrations are the result of gas leaks that have a massive impact on the atmosphere, and play a key-role in the ozone production of the MCMA.[1] Furthermore, the geographical location of the city makes the dispersion of pollutants difficult, especially during winter months, which increases health problems. Therefore, the use of solar water heaters is proposed as a strategy for reducing the amount of fuel burned to accomplish industrial and domestic processes. This could result in the overall reduction of harmful emissions, with a positive impact on the population's health.

Higher cost, compared to traditional systems, is often the reason that consumers may not consider solar water heaters as a viable option, even though solar technologies are inherently non-polluting and are relatively independent from fossil-fuel price increases. A simple payback period analysis may offer the prospective investor a general idea of the economic benefits that a solar water heater system can provide. It identifies the amount of time required for the savings generated by the SWH system to equal the cost of implementing the option. Expressed as a formula:

$$\text{Simple payback} = \frac{\text{Initial cost}}{\text{Annual savings}}$$

Nevertheless, the simple payback analysis fails to consider the time value of money and the impact of inflation that affects energy prices in general.[2] However, other methods of analysis should be used if a more in-depth study is required. Life cycle

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[1] CONAE, citing a study made by Blake and Sherwood.

[2] Professor Martínez-Strevel, from the National Autonomous University of Mexico (UNAM), has proposed a payback method that incorporates the inflation ratio of the cost of fuels for a given period of time, and the estimates savings provided by a solar system (Martínez-Strevel, 13). See appendix A page X

costing, for instance, considers the accumulation of costs of a product over the entire period of life, e.g. costs of purchase, installation, maintenance, and operation, as well as a present worth analysis.[3]

Economic evaluation based on the cost of fuels, although important, should not be the sole factor in the consideration to substitute traditional methods for water heating in the MCMA. Due to the volume of fuel consumed by industrial and commercial applications, the payback period for solar installations is usually shorter in this sector than the payback period offered for dwellers. Although the performance of domestic heaters is good, an influential element to persuade householders to adopt solar water heaters could be the inconvenience that LPG home delivery represents for a vast majority. Each year thousands of homeowners complain before the Consumers' Protection Office about the inadequate service provided by gas companies. Complaints vary from late delivery and illegal price-hikes, to the failure to repair leaks within a reasonable period of time. As a consequence, accidents occur frequently.

The enforcement of interaction between research centers and the industrial sector, the capital goods industry in particular, with the object of standardizing equipment and reducing production costs[4], is especially important in the achievement of major

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[3] Present worth analysis represents the present value of savings. It is based on the concept that a dollar received today is worth more than a dollar received at some time in the future (*Total Energy Management*, 56).

[4] As proposed by Vargas as a part of the three major guidelines to promote alternative energy resources (Vargas, 188-89).

acceptance and successful introduction of the utilization of solar thermal technologies on a mass scale.[5]

In future years, the Mexican solar energy industry[6] faces the challenge of increasing awareness in order to achieve a more prominent spot in the market place. The possibilities of success would increase with adequate promotion of the solar benefits among four principal sectors: the general public, the construction industry, enterprise owners, and governmental groups. The general public should be provided with explicit information, aimed at advising and educating them on the use of solar technologies. Pamphlets, catalogues, and Internet sites are some methods through which familiarize the potential user with the benefits of solar energy. Pricing and technical information is difficult to obtain. A more open attitude from dealers and manufacturers about sharing this kind of material with the general public, developers, and researchers should help to better evaluate this technology. The construction industry should also be well informed about the use and implementation of solar systems, as they could, from the initial stages

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[5] The elaboration of official regulations and national standards should also prevent inefficient technologies affecting the image of solar energy technology. Special attention should be paid to providing qualified service and technical support.

[6] Universities and other institutional research centers have, for a long period of time, been the only organizations dedicated to solar technology development in Mexico. Nevertheless, some efforts have been made throughout the years to expand awareness on solar energy and to link academic resources to industry. The concern of a number of specialists and manufacturers interested on creating a forum to exchange information and contribute to the promotion of solar energy in Mexico, lead to the creation of the National Association of Solar Energy (Asociación Nacional de Energía Solar, ANES). The Association, established in 1980 as an independent civil society, now assembles academic staff, professionals, solar business related people and students interested on the solar field.

of design, be considered as an integral part of the building, thus facilitating installation and enhancing overall performance.[7]

For decades, the high energy-use sectors have been implicitly encouraged the use fossil fuels through subsidy policies that artificially reduce the cost of fuels. However, governmental organizations should consider the preservation of human health and the environment as a priority, not as a benefit which is secondary to economics while developing future energy plans for Mexico.[8] If, for economic and political reasons, these subsidies are unlikely to disappear in the short-term, renewable resources should be encouraged with comparable stimulus.

This thesis is a review of the present circumstances most likely to be considered in the selection of solar energy as an alternative technology to satisfy hot water requirements in a number of businesses and services. The next step would involve a more detailed study of hot water consumption for the various sectors, as well as a survey of the available solar systems in Mexico, in order to provide more precise information about the feasibility of implementation.

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[7] See appendix C

[8] The National Committee for Energy Saving (Comisión Nacional para el Ahorro de Energía, CONAE) has already started a number of programs aimed to standardize, offer technical assistance, and promote the rational use of energy and energy-saving strategies throughout the country.

Appendix A

Economic evaluation of a solar water heater system

Solar water heater system for a hotel	
Place:	Manzanillo, Colima, Mex.
Number of guests:	300
Annual occupancy rate:	60%
Daily hot water consumption:	35 l/guest
Temperature of water:	50°C
Estimated fuel savings provided by the solar system:	80%
Traditional system:	1 firetube boiler
Capacity:	70,560 Kcal/hr
LPG consumption	9.3 l/hr
Gas storage:	2800 l tank
Cost of system, including installation:	$ 24,631.00

Solar system:	Solar water heaters. Absorber plate 100% copper, 1 cover
Size of system:	87.4 m^2
Hot water storage:	5000 l tank
Cost of system, including installation:	$ 73,000.00
Annual LPG consumption:	50,000 l
Average price of LPG (1995)	$0.83/l
Annual inflation rate for LPG (1995)	31%

Economic evaluation of a solar system
Source: Martinez-Strevel, 1996
Continue...

Annual cost of fuel:					
					Cost of fuel without solar system
1st. Year	Annual consumption	*	LPG average price	=	$ 41,500.00
2nd. Year	Annual consumption 1st. Year	*	Annual inflation rate for LPG	=	$ 54,451.61
3rd. Year	Annual consumption 2nd. Year	*	Annual inflation rate for LPG	=	$ 71,445.25
			Total	=	$167,396.86
Savings generated by solar system:					
					Savings
1st. Year	80 % of annual consumption	*	LPG average price	=	$ 33,200.00
2nd. Year	Savings annual consumption 1st. Year	*	Annual inflation rate for LPG	=	$ 43,561.29
			Savings for 2 years	=	$ 76,761.29
3rd. Year	Savings annual consumption 2nd. Year	*	Annual inflation rate for LPG	=	$ 57,156.20
			Total savings for three years		$210,678.78

Economic evaluation of a solar system
Source: Martinez-Strevel, 1996

Appendix B

Prices of solar water heaters in Mexico *

Estimate cost per square meter	
Type of collector	price
Polypropilene	$520-$610
Copper plate without cover	$435-$500
Aluminium and copper plate with cover	$550-$870
Copper plate with cover	$684-$805

Note: Prices in Mexican pesos as for June 1998

Source: Ing. Rodolfo Martínez Strevel, UNAM, 1998

Estimate cost of storage tanks	
Capacity (l)	price
120	$ 1,950
300	$ 3,765
500	$ 5,145

Note: Prices in mexican pesos as for June 1998

Source: Ing. Rodolfo Martínez Strevel, UNAM, 1998

Manufacturer/dealer: **Sunway de México.**			

System that provides hot water for domestic use			
Type of collector	Copper plate and piping with glass cover, 1.01X2.09 m		
		price per unit	total
Number of users	6		
Collectors required	2	$ 1,800.00	$ 3,600.00
Storage tank, 350 l	1	$ 5,600.00	$ 5,600.00
Anti-freezing valve	1	$ 900.00	$ 900.00
Installation		$ 6,000.00	$ 6,000.00
			$ 16,100.00
Note: Prices in Mexican pesos, for October 1999, includes tax.			
Total area of system: 4.22 sq.m			
Made in Mexico			

Manufacturer/dealer: **Instalaciones Técnicas Especializadas**			
System that provides hot water for domestic use			
Type of collector	Copper plate with glass cover, 1.20X0.90 m		
		price per unit	total
Number of users	6		
Collectors required	5	$ 2,125.00	$ 10,625.00
Storage tank, 300 l	1	$ 3,780.00	$ 3,780.00
Storage tank, 150 l	1	$ 3,132.00	$ 3,132.00
Anti-freezing valve	1	$ 638.00	$ 900.00
Installation		n.a	
			$ 18,437.00
Note: Price in Mexican pesos plus tax (15%). October 1999.			
No installation cost provided,			
Total area of system: 5.4 sq. m			
Made in Mexico			

Manufacturer/dealer: **Sol-a-iris**		
Type of collector	Polypropilene, 1.22X2.44 m	
		price per unit
		$ 2,750.00
Note: Imported collector, no more information provided. October 1999.		

Technical specifications for 4 commercial solar water heaters

Type of collector	Polypropilene	Copper plate and piping without cover	Aluminium plate and copper piping with cover	Copper plate and piping with cover	units
Insulation material's thickness	-	-	0.01	0.01	m
Insulation material's conductivity	-	-	0.036	0.036	W/m°K
Distance between plate and cover	-	-	0.02	0.02	m
Collector's length	2.95	2.11	1.70	2.11	m
Collector's width	1.22	1.18	1.00	0.90	m
Area	3.6	2.50	1.70	1.90	m^2
Plate's absorptivity	0.88	0.88	0.88	0.88	
Plate's emissivity	0.90	0.88	0.88	0.88	
Cover's emissivity	-	-	0.88	0.88	
Collector's pipes length	2.95	2.0	1.6	2.0	m
Number of glass covers	-	-	1	1	
External diameter of pipes	0.006	0.013	0.013	0.013	m
Internal diameter of pipes	0.004	0.011	0.011	0.011	m
Distance between pipes	0.0075	0.15	0.15	0.15	m
Plate's thermal conductivity	-	385	211	385	W/m°K
Joint's conductivity	-	33	5	33	W/m°K
Plate's thickness	-	0.0002	0.00036	0.0002	m

Note: Trade marks not provided

Source: Ing. Rodolfo Martínez Strevel, UNAM, 1998.

Appendix C

Basic requirements for the good performance of a solar water heater system[1]

Climate and regional considerations. Specific regional climatic considerations include:

Natural factors:

- Sun altitude and declination, for consideration of collector aperture tilt and shading.
- Orientation –due south vs. magnetic south—to determine orientation of collectors and building geometry (in the case of new constructions)
- Topography, for consideration of building into slopes, earth berming, and otherwise maximizing southern exposure and minimizing others.
- Altitude, for the effects of atmospheric density
- Vegetation, as it affects shading, reflection and air movement
- Ground temperature, as it affects ground water temperature and earth exchange cooling
- Water table height, for considerations of excavation, burying of storage elements, and wetting of insulation
- Water quality, its mineral content, pH, etc, when used for heat transfer fluid or thermal storage

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[1] Adapted from *Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings.*

Man made factors:

- Density and growth of development, with relation to solar rights, shading, glare, and obtrusive installations
- Pollution of air, as it affects insolation, corrosion of exposed parts, stain and dirt deposits on collector cover plates or glazing
- Building materials and architectural character, consideration of mass and geometry
- Building codes, to the extent that they constrain solar applications

Climatic factors:

- Temperature: annual average, seasonal and daily
- Solar radiation: annual, monthly, daily, hourly
- Wind or air movement: direction, velocity, frequency
- Relative humidity
- Rainfall, snow, freezing rain, etc.

Site considerations. Achieving an optimum orientation for the building and/or collector apertures is of primary importance. During the winter months, approximately 90% of the sun's energy occurs between the hours of 9:00 a.m. and 3:00 p.m. It is important that solar collection surfaces not be significantly shaded during this time.

Building/solar system interaction. Solar components should be located where the potential for their misuse is minimized. The proximity of system components to sidewalks and playgrounds should be examined to minimize potential misuse or vandalism. Building exhausts, plumbing vents, or other air discharge openings through roofs or exterior walls should not be located so that their emission will cause the deposition of grease, lint, condensation, or other deleterious materials on solar components, especially apertures or collector glazing. Similarly, solar components should not interfere significantly, either physically or aerodynamically, with building vents, flues, and exhausts.

Domestic hot water. The combined solar and auxiliary domestic hot water system shall efficiently utilize solar energy to reduce the consumption of depletable energy while providing domestic hot water at required temperatures and delivery rates.

Temperature for domestic hot water. The system (combined solar and back-up system) should be capable of providing hot water at a tap temperature of up to 60°C.

Domestic daily water use rate. The hot water system shall be designed to provide daily hot water usage for single family and multifamily dwellings of up to 20 units based on 76 l/day per person for the first two persons and 57 l/day for each additional person with a minimum usage of 150 l/day. Daily hot water usage for each dwelling unit in a larger multifamily building shall be based on 150 l/day for buildings having 21 to 200 units and 130 l/day for buildings having over 200 units.

Collector orientation. The collector array shall be positioned so that the seasonal/annual incident solar radiation per unit area shall not be significantly less than the seasonal/annual incident solar radiation on a reference collector array at optimum collector orientation with no shading, except where special circumstances require non-optimum orientation.

Thermal storage performance. The thermal storage subsystem shall be capable of efficiently accepting thermal energy, storing it, and releasing it to satisfy partially of fully the space hot water load.

Thermal energy loss. Thermal energy loss from thermal storage, including loss due to air leakage (in or out) shall not exceed 15% of the energy input of the storage subsystem for those months in which the load exceeds the collected amount of solar energy.

Energy transport performance. The energy transport system shall be capable of efficient transfer of thermal energy among or between the various components and subsystems.

Thermal energy loss. Under normal operating conditions, thermal energy loss from the energy transport system shall not exceed 15% of the energy to be transported.

Operating energy. Under normal operating conditions, operating power for fluid transport of solar thermal energy to or from storage shall not exceed 10% of the energy transferred.

Control performance. The control system shall be capable of proper and efficient regulation of all other systems to fulfill the water system requirements.

Collector fluid circulation. The circulation of heat transfer fluid through the collector shall occur only when useful heat can be collected except as required for freeze protection, heat rejection, or dumping of excess energy.

Priority of energy use. The controls shall prioritize the use of energy so that solar energy is first applied toward attempting to meet the load, after which auxiliary thermal energy is used to supply the balance, as necessary.

Collector selection. The solar collector shall be selected based on efficient operation in the desired operating temperature range of the equipment to which the collected solar energy is delivered.

Fluid flow rates. Heat transfer fluid flow rates shall be compatible among the various subsystems with regard to capacity and heat transfer rates. Heat exchangers and other devices shall be sized to effectively transfer energy from one subsystem to another.

Auxiliary equipment selection. Auxiliary energy equipment shall meet or exceed the minimum efficiency as required in the applicable energy code, standard or regulation. Auxiliary energy equipment shall be integrated with the solar hot water system to minimize the use of depletable energy by the system.

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