Retrofit Demonstration in Brazilian Commercial and Public Buildings

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ABSTRACT

In order to help the development of energy efficiency building standard in Brazil , to demonstrate state of art technologies and to encourage the use of hourly energy simulation tools the National Energy Conservation Program (PROCEL) has started the "6 Cities Project". The project is being developed in six cities around the country. For this project a standard methodology was developed and applied. The methodology consists of a survey in the local utilities to establish the highest energy consumers in the commercial and public sector. A data-base is being created with information on energy consumption intensity and demand intensity in 15 buildings in each city. The data-base was designed to help the standards development. Among those buildings, in each city, two were selected, one is a public building and one a private building, for a detailed energy audit. The audit data was used to calibrate a DOE2 simulation model. Simulations were performed and state of art technologies for energy efficiency are being tested and will be implemented. An after retrofit monitoring program is planed. In this paper the results of the first buildings will be showed.

Introduction

Energy used in buildings is about 45% of the total electric energy consumption in Brazil (MME 1996). Figure 1 shows the evolution of the energy consumption in the residential, commercial and public sectors from 1980 to 1995.

The residential sector accounts for half of this consumption and the other half is in the commercial and public sectors. The growth of the residential sector was the largest mainly due to more houses being connected to the system and to the economic stability achieved in 1995 that resulted in high sales of household appliances. The evolution of the growth in the three sectors in the last years can be seen in Table 1. The highest accumulated growth in the last years is in the commercial sector. The main factors that influenced the growth of the commercial sector were: evolution of sub contracting in the economy; expansion and opening of new shopping centres with strong growths of franchising; increasing use of sea ports and high occupancy of beds in hotels in the Northeast (Eletrobras 1995).

Figure 1 also shows the growth of the Gross Domestic Product. It is possible to see that the energy consumption growth is linked to the gross internal product growth, showing no improvement of the energy efficiency in general terms.

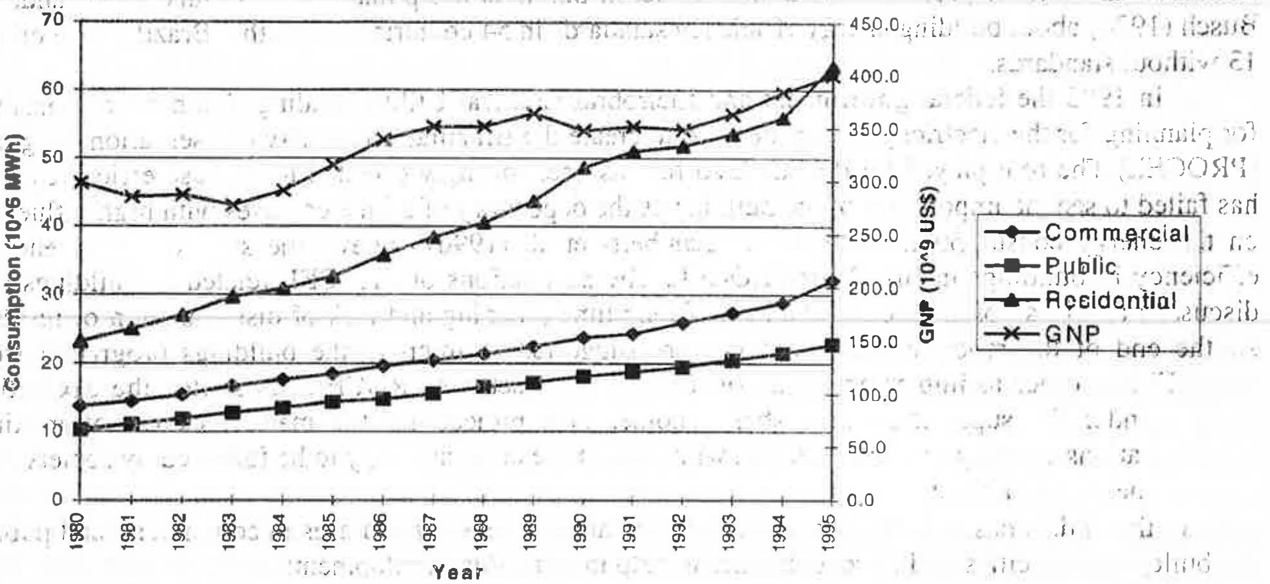

Figure 1. Electric energy consumption in the residential, commercial and public sectors compared to the gross domestic product.

Table 1. Growth of sectors from 1991 to 1995 in percentage (%).

years	Residential	Commercial	Public
91-92	1.6	6.5	3.9
92-93	3.4	5.7	5.4
93-94	4.3	5.4	4.5
94-95	13.5	11.3	6.4

In the residential sector the end uses directly related to the building design are: hot water, air conditioning and lighting. Due to the mild climate, Brazil has little demand for space heating. A study by Jannuzzi & Schipper (1991) in Rio Claro, São Paulo indicates that these three end uses are responsible for 43% of the total electric energy consumption in this sector. Jorge Wilheim and Associates (1988) shows this value to vary from 45% in summer to 57% in winter in São Paulo. The other end uses not related to building design are due to appliances. The consumption in this sector is expected to grow with the development of the nation mainly due to the bad thermal design of the buildings being built without any consideration of the climate where they will operate, making air conditioning a must for thermal comfort.

In the commercial and public sectors there is a great diversity of end uses. The importance of the building design is related to lighting and air conditioning. Geller (1991) and Jorge Wilheim and Associates (1988) show these end uses to be 64% of the total in average and as high as 86% in banks and offices. In these buildings also the bad thermal design will account for a substantial growth in the energy consumption as for workers productivity and business the investments in thermal comfort are necessary.

Building design in Brazil has not been pushed towards energy efficiency due to the lack of standards and lack of professionals trained to act in this interdisciplinary field. A survey by Janda & Busch (1994) about building energy efficiency standards in 54 countries shows that Brazil is one of the 13 without standards.

In 1985 the federal government and Eletrobras (Federal Utility Holding Company responsible for planning for the electricity sector) decided to create the Brazilian Electricity Conservation Program (PROCEL) The role played by PROCEL so far has been strongly oriented to end use efficiency and has failed to see the importance of the building as the depository of all the end uses with high influence on the energy consumption. A report by Lamberts et al. (1996) reviews the state of art of energy efficiency in buildings in Brazil for PROCEL. The past actions of PROCEL related to buildings are discussed and it is possible to see the lack of long time planning and lack of dissemination of results. At the end of the report a list of action were suggested to improve the buildings program inside PROCEL. In order to implement many of the suggested actions PROCEL has started the Six Cities Project under the supervision of Mabele Thomé. This project has the main objective of making demonstrations of energy efficient retrofit with state of the art technology to be followed by society.

The project aims also at:

- building a data base of energy consumption per area and energy end uses in commercial and public buildings in 6 cities in different climates to help in standards development;
- performing detailed energy auditing of two buildings per city following a standard methodology;
- training simulation experts in 6 cities to spread the use of hourly simulation;
- calibrating DOE2 simulation models of the two audit buildings in each city;
- studying retrofit options for those buildings;
- implementing the retrofit in the buildings;
- after retrofit monitoring to check simulation results.

The six cities chosen were: Florianópolis, Curitiba, Rio de Janeiro, Belo Horizonte, Brasilia and Salvador. The location of the cities is given in figure 2.

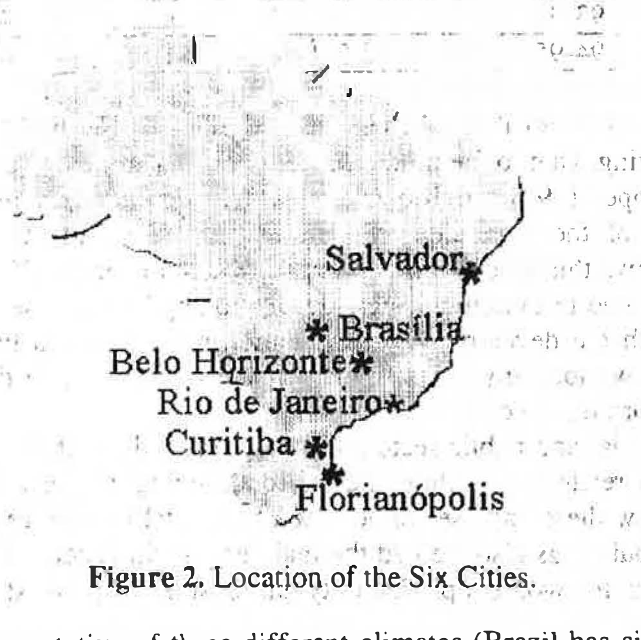

Figure 2. Location of the Six Cities.

The six cities are representative of three different climates (Brazil has six) covering the most densely populated area of the country.

This paper presents the methodology used, the energy consumption data base, techniques used for simulation calibration and the first retrofit studies.

Methodology

The methodology used in the 6 cities is the same and is based in 8 steps that are described bellow.

- **Initial Selection** - The initial selection consists of choosing 15 buildings among the commercial and public consumers from the utility of each city. The buildings must be of office use, have the highest monthly energy consumption, be of easy identification for the general population and receive only one electricity bill (to have a demand meter recorder).
- **Initial Analysis** - Among the 15 buildings 10 are selected and classified based on the mean monthly energy consumption per area and on demand per area.
- **Visit to the Buildings** - A technical visit of one day to the 2 buildings with highest classification in the previous analysis is done to check for building owner interest in participating in the project and observe the potential for gains with retrofit. In case of low potential of retrofit gains or no interest from the owner point of view, the next building in the classification is visited.
- **Owner Compromise** - The building owner will sign a letter of interest in the project and will assume the responsibility of implementing the cost-effective retrofit options with the help of low interest rate loans.
- **Retrofit Study** - For the retrofit study a detail energy audit is performed and a simulation model using DOE2.1E is calibrated. Retrofit alternatives are simulated and cost-effectiveness is analysed.
- **Negotiation of Loan and Retrofit design and implementation** - Low interest rate loans were made available in order to increase investments in energy efficiency.
- **After retrofit monitoring** - After retrofit monitoring is considered a very important part of the project in order to check the fidelity of the simulation results and possible problems with retrofit implementation. This information will be used in future program implementation in other cities.
- **Dissemination of results** - Dissemination of results is done throughout the project for several audiences. Special dissemination for the general public and technical community is planned to widespread the demonstration of potential energy efficient retrofits and their cost-effectiveness.

Energy Consumption Data Base

So far only five cities have finished the first steps of the methodology. The results are presented in Table 2 in terms of mean monthly energy consumption per area and demand per area.

In order to allow a better correlation of data from Table 2 with climate, Table 3 shows the cooling degree hour for the cities

Table 2. Mean Monthly Energy Consumption per Area (MMEC, kWh/m^2) and Demand per Area (D, W/m^2) for 5 cities.

City	Variable	Average	Minimum	Maximum	Stand. Dev.
Salvador	MMEC	24.34	4.15	79.38	20.27
	D	85.04	29.49	223.74	50.13
Brasilia	MMEC	19.71	5.87	84.55	21.15
	D	94.21	24.48	311.76	80.40
Belo Horizonte	MMEC	18.16	6.09	59.64	14.91
	D	38.76	11.53	112.97	30.11
Rio de Janeiro	MMEC	15.51	3.46	63.57	15.90
	D	58.87	21.25	120.93	32.48
Florianópolis	MMEC	15.98	5.86	41.26	10.81
	D	70.35	26.00	120.50	23.19

Table 3. Cooling degree hour for a temperature base of 24 °C (Goulart, Lamberts & Firmino 1997). Data for Belo Horizonte was not available.

City	Number of degree hours
Salvador	16113
Brasilia	6184
Rio de Janeiro	10981
Florianopolis	4517

Comparing the average MMEC with cooling degree hour, apart from Rio de Janeiro the other cities show a good correlation of energy consumption with cooling demand. Comparing the maximum MMEC, Brasilia shows an unexpected behavior with the highest value. Brasilia shows also the highest demands (average and maximum).

Simulation Calibration

The building energy audits followed a standard methodology and consisted in gathering data on electricity bills, occupants population, lighting power density, air conditioning system and plant, equipment plug loads and patterns of use. A walk through was also done to look for important details for the simulation. The methodology used for calibrating the simulations was developed from the work of Kaplan (1992), Koran et all. (1992 and 1993) by Pedrini (1997). Total energy demand was monitored every 15 minutes for 2 to 3 months. End use of energy was measured for air conditioning, lighting and plug loads. The air conditioning system demand and performance was monitored for a week in order to check its efficiency (in accordance to ARI). Set points of cooling systems were also measured. Figure 3 shows electric energy consumption for a day divided by end uses. This data was used to establish typical schedules of use for lighting and plug loads.

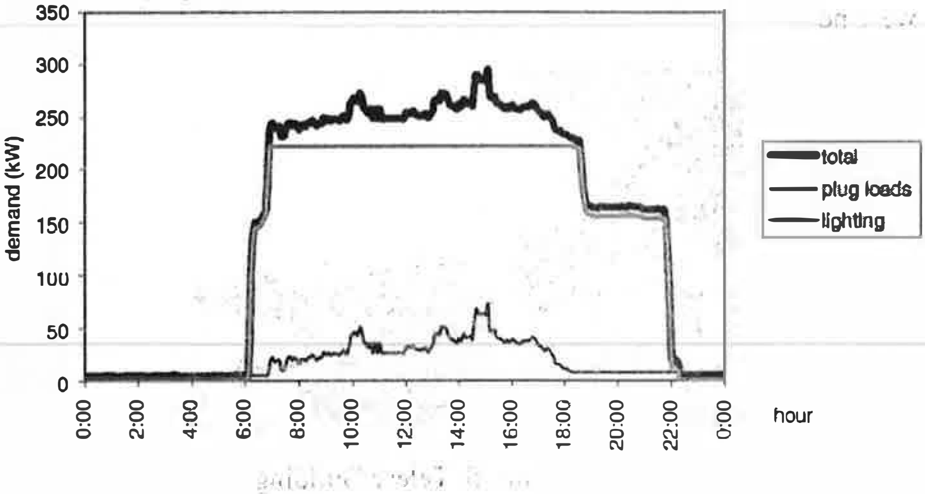

Figure 3. Electric energy consumption of one transformer for a day in Eletrosul building divided by end uses.

This data was then used to calibrate a building simulation model in DOE2.1E.

Florianópolis was the first city to finish the simulation calibration. In Florianópolis, instead of two, three buildings were studied. The buildings were: Eletrosul, Telesc and Fiesc.

Eletrosul is an office building of 29963 m^2 and was built in 1978. Figure 4 shows the main façade of the building. The building has 5 floors, 3 above and 2 bellow ground. The lighting power density is 16.32 W/m^2 for the whole building and 22.82 W/m^2 in office areas. The air conditioning system consists of 2 centrifugal chillers of 420TR for daily operation and an alternative chiller of 100TR for over night operation. The total installed capacity is 940 TR. The efficiency of the centrifugal chillers was found to be 1.0 kW/TR compared to 0.8 when they were new. The efficiency of the alternative chillers was found to be 1.4 kW/TR compared to 1.0 when they were new.

Figure 4. Eletrosul Building

Telesc is an office building of 10.250 m^2 and was built in 1976. Figure 5 shows a façade of the building. The average lighting power density is 22 W/m^2 and the air conditioning system consists of 3 alternative chillers of 80TR and several package systems adding more 120TR. The total installed capacity is 360 TR. The efficiency of the alternative chillers was found to be 1.1 kW/TR. compared to 0.9 when they were new.

Figure 5. Telesc Building

Fiesc is an office building of 10.900 m^2 and was built in 1983. Figure 6 shows the main façade of the building. The average lighting power density is 16.2 W/m^2 and the air conditioning system consists of 2 alternative chillers of 240 TR and several package systems adding more 44 TR. The total installed capacity is 524 TR. The efficiency of the alternative chillers was found to be 0.9kW/TR. compared to 1.1 when they were new.

Figure 6. Fiesc Building

The first simulation models were developed from the basic knowledge of occupants population, lighting power density, equipment plug loads, air conditioning system and patterns of use.

Simulation calibration was performed by creating a typical day hourly demand evolution from the monitored data and using this to create schedules of operation based on the patterns of use and equipment power demand signatures on the integrated demand curve. The air conditioning real efficiency was also used in the calibrated model. The comparison of the calibrated simulation model with real monthly energy consumption data for the buildings is showed in figures 7, 8 and 9.

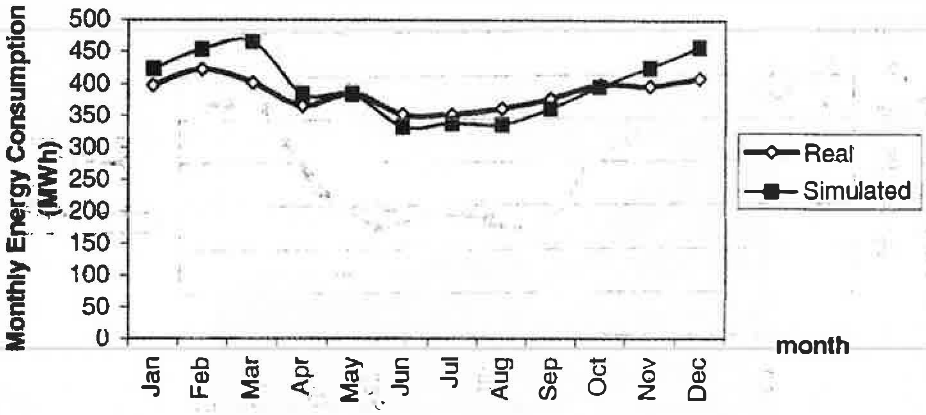

Figure 7. Comparison of the calibrated simulation model with real monthly energy consumption for the Eletrosul building.

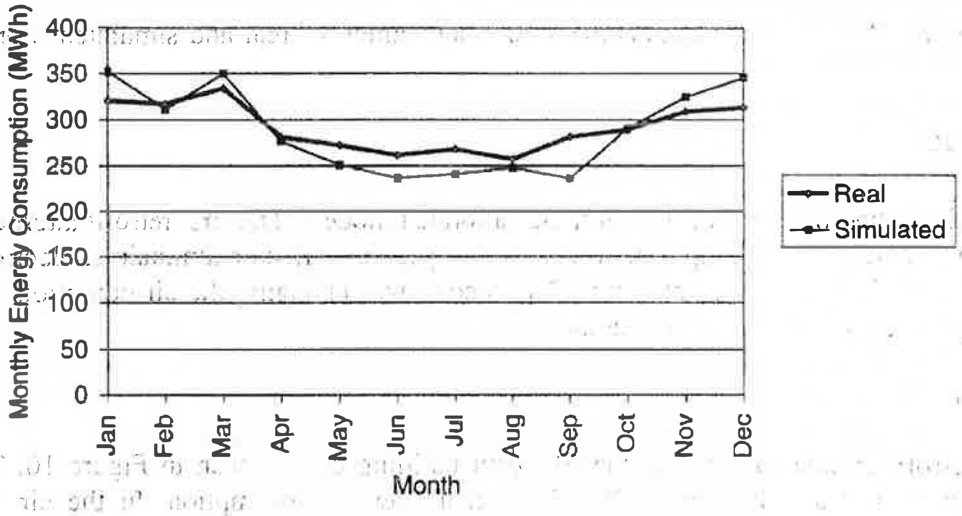

Figure 8. Comparison of the calibrated simulation model with real monthly energy consumption for the Telesc building

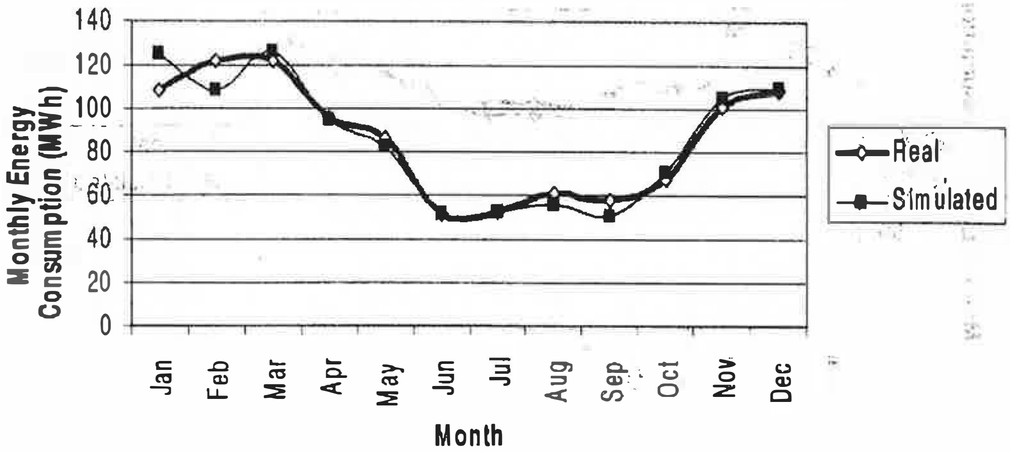

Figure 9. Comparison of the calibrated simulation model with real monthly energy consumption for the Fiesc building

Results for the three buildings show a good agreement of real and simulated monthly energy consumption

Retrofit Studies

Retrofit studies were performed with the calibrated models. The first retrofit alternative studied was changing the artificial lighting system and using specular reflector luminaires, electronic ballasts and 32W high efficiency fluorescent lamps. The second was changing the air conditioning plant and implementing some automation in its operation.

Eletrosul Building

The retrofit simulated gains in the Eletrosul building can be seen in Figure 10. The lighting system retrofit caused a reduction of 20% in annual energy consumption. In the air conditioning system, the two old centrifugal chillers were changed by one new centrifugal chiller of 410 TR and higher efficiency (0.49 kW/TR). The alternative chiller was retrofitted and coupled to a thermal storage water tank. The reduction with the total retrofit (lighting + air conditioning) was 25%. The estimated pay back of the investments in lighting and air conditioning retrofit is 4.3 years. The pay back might seem to high but as the air conditioning plant is 20 years old its operating conditions are poor and investments are already needed.

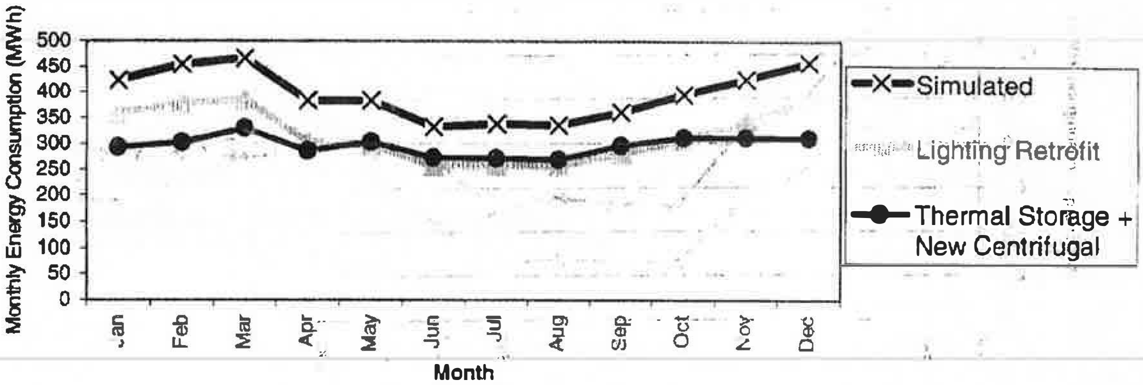

Figure 10. Simualtion of retrofit options in Eletrosul building.

Telesc Building

In the Telesc building only the lighting retrofit was studies so far and the result can be seen in Figure 11. A reduction of 28% was achieved so far but much more is expected in the air conditioning system as many package systems have been added to the building due to lack of capacity by the central system.

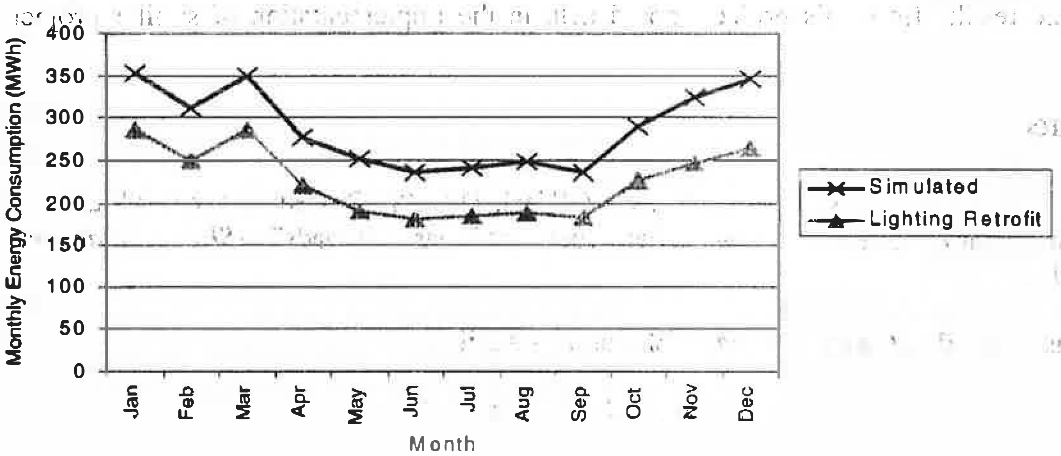

Figure 11. Simualtion of retrofit options in Telesc building.

Fiesc Building

In the Fiesc building also only the lighting retrofit was studies so far and the result can be seen in Figure 12. A reduction of 35% was achieved so far but more is expected in the air conditioning system.

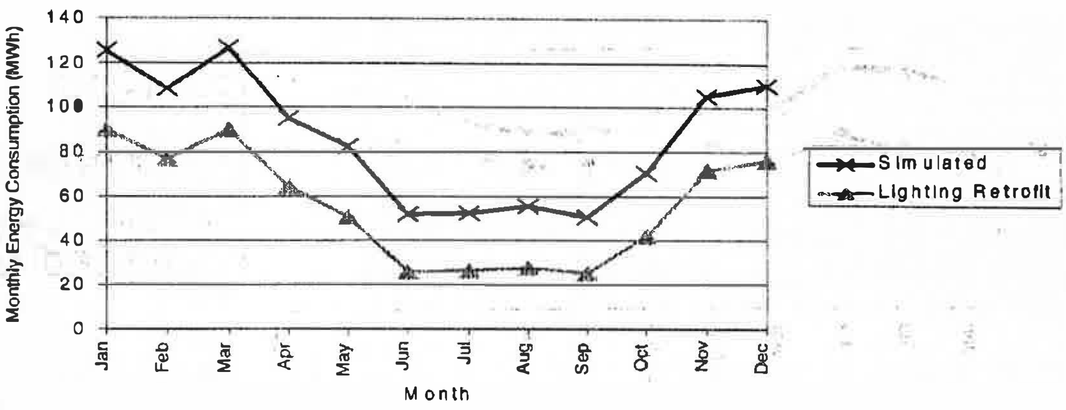

Figure 12. Simualtion of retrofit options in Fiesc building.

Conclusions

The first results from this project are very encouraging. The simulation calibrations for the first buildings showed very good agreement with measured data and allowed more accurate estimation of retrofit benefits. The implementation of the retrofits in the first buildings is expected to start this year and after retrofit monitoring should start next year. Dissemination of results is starting now and dedicated dissemination for different audiences should start this year.

The results from this project should help in the implementation of similar projects in other cities.

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