PROMOTION OF COMPACT FLUORESCENT LAMPS IN ARGENTINE HOUSEHOLDS: IMPACT ON USERS AND ON THE DISTRIBUTION COMPANY

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In a study conducted between Dec. 1999 and Jan. 2000, a number of high-usage incandescent lamps were replaced by compact fluorescent lamps in each of a sample of 10 houses in Buenos Aires. The operating times of incandescent lamps and CFLs that replaced them in previously identified light points were extensively monitored. The principal objective of the measurements was to determine energy savings and change in hourly load shape resulting from lamp substitution. To this end, energy and power demand loggers were installed to replace billing electric meters in all 10 houses. In five of the houses, the activity of the selected lamps was measured, using lighting loggers that record the on- and off- times of these lamps. Moreover, measurements were made to determine changes in lighting levels and power factor as a result of lamp substitution.

In order to determine changes in energy consumption and load curve, the hourly variation for two-week periods with each lamp type was measured. Average savings measured was 0.85 kWh/day (9.4%) of total energy use. For the Argentine system peak demand period (6 to 10 PM), energy savings was 17.0%, while the peak demand per household fell from 0.64 kW to 0.56 kW, a reduction of 12%.

In the five houses with lighting loggers, the hourly variation of lamp use for the same two periods was also compared. The incandescent lamps were used 4.4 hours per day while the CFLs were used virtually the same amount of time, 4.2 hours per day. Thus we observed no increase in the use of CFLs with respect to the incandescent lamps.

The total power input of the lamps fell by a factor of 5 (80%) from 845 W to 169 W when the incandescents were replaced by CFLs in these five houses. The incandescents consumed a total of 3.73 kWh/day while the CFLs added up to only 0.71, a reduction of 81%, almost identical to the fall in power.

According to our measurements, the average residential user in Buenos Aires would save $21 a year in electricity while paying $5.36 extra annually for lamp purchases. We estimate net savings to residential users nationwide of replacing two incandescents by CFLs to be almost $300 million a year.

With the current tariff scheme, electricity distribution companies in Argentina are likely to reduce their profits as a consequence of a highly successful program to promote CFLs. We suggest that these companies be given incentives, through the tariff structure, so that they may actively promote energy efficiency among their residential customers.

HOURLY LOAD CURVE IMPROVEMENT THROUGH THE PROMOTION OF COMPACT FLUORESCENT LAMPS IN ARGENTINE HOUSEHOLDS

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INTRODUCTION

In the Argentine residential sector, efficient lighting offers a significant energy savings potential. Although refrigerators and freezers consume a similar amount of energy and with large energy savings potential, the longer life time of the equipment implies a slower turnover and slows the energy savings.

Moreover, residential lighting makes the most significant contribution to the hourly peak demand, not only in the sector but in the entire national grid, see Dutt and Tanides (1). Thus, the replacement of incandescent lamps by compact fluorescents permits both energy savings and peak load reduction. The most convenient replacement option is a compact fluorescent lamp (CFL) that incorporates an electronic ballast.

DESCRIPTION OF MEASUREMENTS

As part of the ARGURELEC[1] project, EDENOR and the University of Buenos Aires conducted a study to determine the impact of replacing intensively used incandescent lamps by CFLs on energy consumption, load curve and harmonics in a sample of 10 houses.

To this end, energy and power demand meters were installed at the entrance to each of the houses (here identified as Z1 to Z10) replacing the standard billing meter by an ABB Alfa 1, which performed both the billing function as well as recording energy consumption every 15 minutes, permitting power demand to be determined.

In 5 of the houses (Z1 to Z5), the on- and off-times of selected lamps were recorded using lighting loggers (HOBO from Onset computers), located close to each lamp. The threshold levels of the loggers were adjusted so that they only record the lamp in question, and neither other lamps nor daylight. In some cases, this required placing elements that kept light from other sources from reaching the sensor of the lighting logger.

In general, two lighting loggers were installed in each house and correspond to the light points most used (see *Selection of lamps to replace*, below). However, one of the lamps in Z3 corresponds to an outdoor lamp where it was not possible to exclude daylight from the sensor. The on- and off-times of this lamp were simulated using data provided by the family.

Besides energy and power demand, additional measurements were made to determine changes in lighting levels and power factor as a result of lamp substitution.

Selection of lamps to replace. The replacement of incandescent lamps (INCs) by CFLs is more cost effective for those INCs of higher power input and longer on-times per day. In each house, the lamp usage pattern was surveyed in order to determine the light points were lamp substitution would be most cost effective. A factor of 5 to 1 in the power of incandescent and equivalent CFL was used for the substitution. This factor corresponds to the equivalency in luminous flux (lumens) declared by the lamp manufacturers. Specifically, 100 W INCs were replaced by 20 W CFLs, 75 W INCs by 15 W CFLs and 60 W INCs by 12 W CFLs.

Analysis periods. Two two-week periods were identified (around summer solstice): the first (called "INC"), lasts from 9 to 22 Dec. 1999 and corresponds to the period in which the incandescent lamps were in use in the selected light points; CFLs were in use in these light points during the second period, ("CFL"), which lasted from 30 Dec. 1999 to 12 Jan. 2000.

RESULTS OF MEASUREMENTS

Whole-house energy consumption and savings, separated into the three demand periods (Valley, Shoulder and Peak) for the periods INC and CFL for the 10-house average are shown in Table 1.

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[1] *Promoting the rational use of electricity in Argentina (ARGURELEC)* is a project within the ALURE program of cooperation between the European Union and Latin American countries in the area of energy. The participants in ARGURELEC include the Argentine Secretary of Energy, the electricity distribution company EDENOR, and three European partners: ICAEN (Spain), ADEME (France) and FAST (Italy). There was a separate agreement between EDENOR and the Faculty of Engineering, University of Buenos Aires that contributed to the results reported here.

Table 1. Average energy consumption and savings in 10 houses with incandescent lamps (INC) and CFLs in selected lamp points, in kWh/day and (%)				
Period	Valley (23–05 h)	Shoulder (5–18 h)	Peak (18-23 h)	Total
INC	2.330	4.165	2.604	9.098
CFL	2.109	3.976	2.162	8.247
Sav.	0.221 (9.5%)	0.189 (4.5%)	0.442 (17.0%)	0.851 (9.4%)

The overall savings is 0.851 kWh/day, 9.4% of consumption with incandescent lamps. The savings for the individual houses vary from 0.5% (Z1) to 25.7% (Z8). One should keep in mind that the measurement periods correspond to summer solstice (in the Southern Hemisphere) when the days are longest and the use of electric light is least. Thus annual-average lighting energy consumption and potential energy savings are underestimated by these measurements. Figure 1 summarises dispersion in percent energy savings in 10 houses for different times of the day.

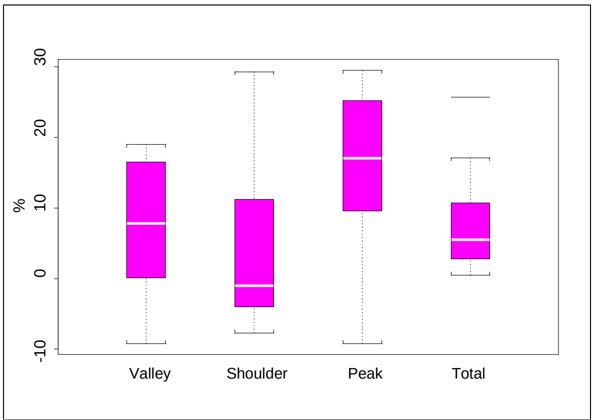

Figure 1. Boxplot of percent electricity savings from CFL use in 10 houses, at different hourly demand periods. (Note that the centre line inside the box shows *median*, not *mean* value.)

The total hourly demand of the 10 houses for the two periods is shown in Fig. 2. Savings are noticeable from about 5 PM to 1 AM, with consumption remaining the same for the rest of the day.[2] Average peak demand falls from about 0.64 kW to 0.56 kW as a consequence of replacing two incandescent lamps by CFLs, a reduction of 12% of the total demand. Energy savings during the peak period were 17% compared to 4.5% in the Shoulder and 9.5% in the Valley (see Table 1).

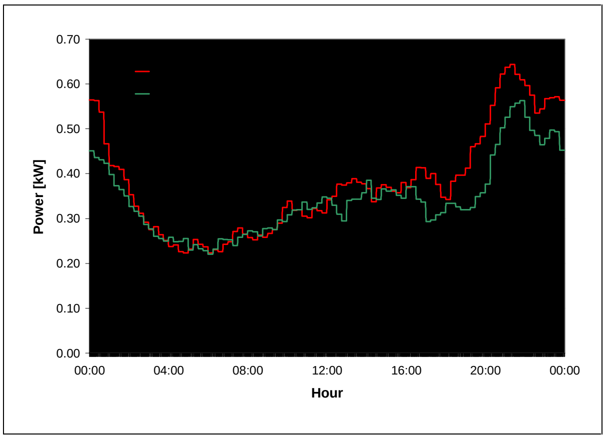

Figure 2. Total hourly demand for the two periods (Upper line corresponds to incandescent period).

In the 5 houses (Z1 to Z5) where lighting loggers were installed at the light points where lamps were replaced, we can directly measure lamp usage —and estimate lighting energy consumption— during the two measurement periods. In each case, a significant reduction in energy demand can be seen. Fig. 3 shows total electricity demand for all the lamp points monitored, for each period. While the total power of the incandescents is 845 W, the actual diversified maximum power demand of these lamps was around 600 W and occurred at about 9 PM, showing considerable demand coincidence of the lamps with one another and with the peak demand period (6 to 11 PM). The corresponding values for the CFL period are 169 W (installed) and 100 W (measured, again around 9 PM). While the installed power bears a 5 to 1 ratio, as expected, the ratio of measured maximum power is about 6 to 1, suggesting less lamp use at 9 PM, during the second period.

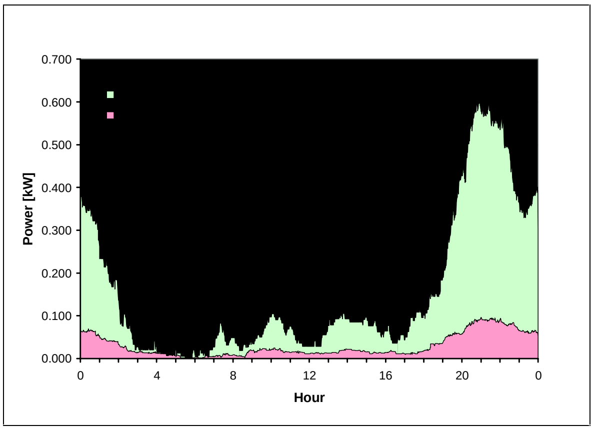

Figure 3. Lamp 5 houses daily average demand during two 14-day periods.

According to these measurements peak demand reduction averaged over these 5 houses was 0.1 kW.

Lamp energy consumption during the two 14-day periods is shown in Table 2. Over the two-week measurement period with incandescents, these lamps used 3.734 kWh/day, while the CFLs used only 0.711 kWh/day, a

[2] Because the measurement period included weekends and New Year's Eve (though not Christmas), there is considerable light use late at night.

reduction de 81%. This is virtually identical to the reduction in power input (80%).

Table 2. Selected lamp energy consumption, INC vs. CFL.

	Installed power	Average energy consumption and savings (kWh/day)			
Period	W	Valley	Shoulder	Peak	Total
INC	845	1.002	0.722	2.016	3.734
CFL	169	0.213	0.164	0.334	0.711
Sav.		0.789 (80%)	0.558 (77%)	1.682 (83%)	3.023 (81%)

Energy use of the measured incandescent lamps and CFLs is compared with total house energy use in Figures 4 and 5, respectively. For the period with incandescent lamps, the energy use of the 9 such lamps monitored was a significant part of overall house energy use during peak periods and the early morning hours. When these are replaced by CFLs, energy use of these lamps is insignificant compared to the total. This confirms that even replacing a few selected lamps per household can produce significant energy savings.

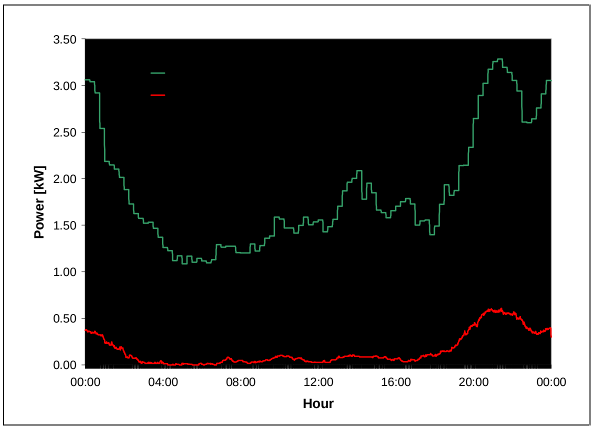

Figure 4. For the 5 houses with lighting loggers: total power demand and power demand of (incandescent) lamps recorded.

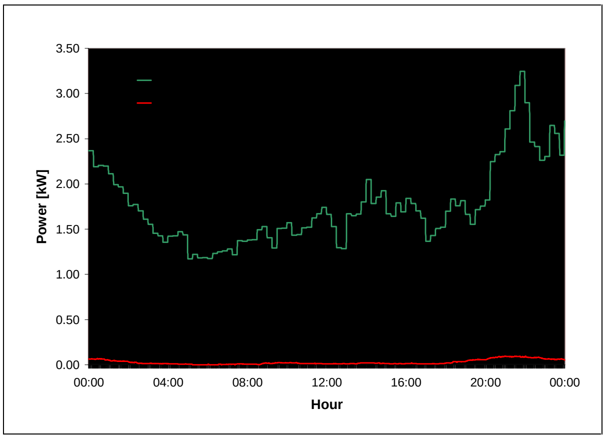

Figure 5. For the 5 houses with lighting loggers: total power demand and power demand of CFLs recorded.

Lamp on-times and cycling. The monitored incandescent lamps were used an average 4.4 hours a day, while the replacement CFLs were used 4.2 h/day. No increase in hours of CFL use was observed. We suspect that this is not necessarily a typical behaviour pattern, for several reasons. First, the measurement period was short, not allowing for changes in lamp usage. Second, the users did not purchase the lamps, so they were not specifically conscious of the lower operating costs of the higher cost CFLs. However, more generally, we may expect CFLs to be used more hours per day than the incandescents they replace. One evidence of this can be readily seen in Buenos Aires. Most outside lamps that are observed lit at night are CFLs; many houses that have incandescent lamps outside tend to keep them off.

Although the most heavily used lamp points were selected for measurements and replacement, only 4 of 9 such points are used more than 2 hours a day. This should be taken into account in programs that estimate energy savings from lamp replacement: replacement is much less cost effective when daily on-times are short.

Another important consideration is the *number* of on- and off-periods. The monitored lamps were operated at daily on- and off-cycles that varied from one to about 14. The life of most CFLs is shortened if they are turned on and off frequently. With CFLs resisting 5,000 to 10,000 cycles, a lamp that is cycled 14 times a day would last from one to two years. The nominal life of a CFL is defined in terms of operation in 3-hour cycles. If a lamp, with a nominal life of 10,000 hours, is turned on once a day and operated for 3 hours at a time, it would last nine years. We believe that CFL use should not be recommended in lamp points where frequent cycling may be expected.

Lamp replacements and lighting levels. Incandescent lamps of 100 W, 75 W, and 60 W were replaced by 20 W, 15 W and 12 W CFLs respectively. Manufacturers claim that the luminous flux levels (lumens) are equivalent for this replacement criterion. We did not measure luminous flux of the lamps. However, we did measure illuminance levels (lux) on typical surfaces in the rooms where lamps were replaced, with the incandescent lamps and with CFLs. The results are summarised in Fig. 6. Illuminance levels fell considerably with CFLs. While this may be due to the different shapes of the CFLs and thus different angular light distribution, we do not believe this to be responsible for the reduction measured. The luminous flux of CFLs depends on position (base up or down) and operating temperature. If differences between laboratory and actual operating conditions lead to significant reduction in light output, more realistic equivalence levels between incandescents and CFLs should be recommended, such as 4:1 power ratio.

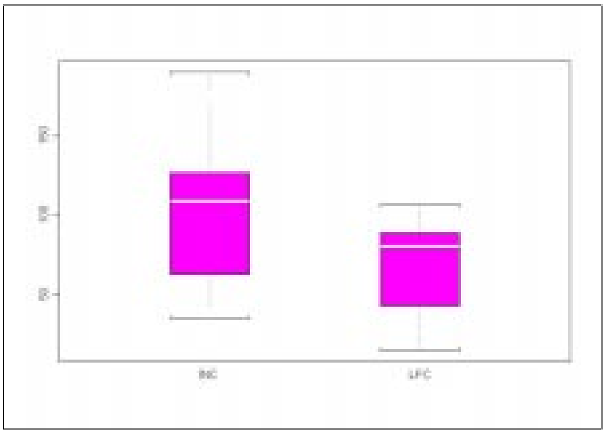

Figure 6. Boxplot of illuminance levels measured on typical surfaces in the rooms where lamps were replaced, with incandescent lamps (mean 109 lux) and replacement CFLs (mean 80 lux).

Power factor. CFLs and other discharge lamps require the use of ballasts which may reduce the power factor (PF) below unity. *Electromagnetic* ballasts do so principally because the current lags the voltage. In this case PF = cos ϕ. The PF may be improved by incorporating an adequate capacitor into the circuit. *Electronic* ballasts, on the other hand, distort the current waveform which results in low PF. While filters may be used to compensate for the harmonic distortion, the CFLs used in this program (like all others sold in Argentina) do not incorporate filters, and operate with Total Harmonic Distortion (THD) in excess of 100% and consequently low PF.

When an incandescent lamp is replaced by a CFL, the PF of the house drops, both because a resistive load is removed and a harmonically distorted load is added. A number of studies have shown that even a large-scale substitution of incandescents by CFLs does not have a significant impact on the distribution network. [Brauner and Wimmer (2); Gothelf (3); Bemis (4); Hanzelka and Ryder (5)].

However, residential users in the Edenor service area (and elsewhere in Argentina) are subjected to a surcharge in their electricity tariffs: there is a penalty of 10% if the PF is below 0.85, and 20% if the PF is below 0.75. Thus the question is: does lamp replacement cause whole-house PF to fall below levels at which the electricity bill is subject to surcharge?.

The whole-house PF at any time depends on the appliances and lights connected at the time. Measurements were made in 6 of the 10 houses reported so far and in 4 others where 2 CFLs with electromagnetic ballasts and 2 with electronic ballasts replaced 4 incandescents, in each case. Residents were instructed to leave lights and appliances operating to simulate operating conditions at 3 AM, 8 AM, 1 PM and 9 PM, and PF measurements were made both with refrigerator compressor operating and with it off. (The refrigerator is a large inductive load.) The results for 9 PM, where the CFLs are likely to have the most impact, show that in some of the houses, the PF falls to levels that are subject to the penalty when lamps are replaced. To be sure, the PF values were already low in these houses and the CFLs are just the last straw. We believe that correcting the PF of the refrigerators may be a better strategy than requiring high power factor CFLs.

ECONOMIC BENEFITS FOR USERS

When incandescent lamps are replaced by CFLs, users save energy and money. On the other hand they have to purchase the CFL and not purchase a number of incandescent lamps.

The cost effectiveness of lamp replacement depends on the price of the CFL and the incandescent lamps, their power input, the electricity tariff, the life of the lamps (expressed in hours), the hours of use per day, and the discount rate used for economic comparisons.

There are two residential tariffs in the service area of the electricity distribution company Edenor: T1R1 and T1R2. As energy savings —through the use of CFLs— reduces energy consumption, the relevant energy tariff is the energy cost, which is 11.7 cents/kWh for T1R1 and 6 cents/kWh for T1R2. With very few exceptions (corresponding to very large consumers) residential users in Argentina are not metered or billed for power demand.

For the 10 houses monitored, average savings per household was 0.851 kWh/day.

Note that the average consumption of the 10 houses in our sample (with incandescent lamps) was 9.098 kWh/day, i.e. 3321 kWh/year, a value considerable higher than the residential average for Edenor in 1999, around 2400 kWh. If we proportionally lower average savings, these would be 0.615 kWh/day (close to the average for the 5 houses with loggers, 0.605 kWh/day), which is equivalent to (365 x 0.615) = 224 kWh/year. Considering that our measurement period was around summer solstice, annual savings should be somewhat higher. We estimate annual average savings in the Edenor service area to be 250 kWh.

The economic value of the savings depends on the tariff. In 1999, residential users in the T1R1 and T1R2 tariffs were divided in a 40:60 ratio. A weighted-average tariff would be $0.084 /kWh, and a 250 kWh/year savings implies an annual cost savings of $ 21.05.

At a retail CFL price of $12, the average lamp cost per house (considering the replacement of 2 lamps) is $24. However, these lamps have a rated life of 6000 hours versus 1000 hours for the incandescents. Considering an average use of 4.3 hours per day for the lamps replaced, annual usage is 1570 hours. The average CFL would last 3.82 years while the incandescent only 0.64 year.

An investment of $24 per house is equivalent to an annual cost of $7.90, considering a 3.82-year life and a 10% discount rate. The annualised cost of the two incandescents (unit lamp cost = $0.75) is $2.54. The additional cost of purchasing 2 CFLs is $5.36 per year.

Thus the average residential user would save $21.05 a year in electricity for an additional lamp cost of $5.36 per year. The benefit cost ratio is 3.9. Considering Edenor's 2.1 million residential users the total savings would be $ (21.05 – 5.36) x 2.1 millions, almost $ 33 million yearly.

Residential tariffs are higher in many parts of the country, and an average value might be $ 0.13 /kWh. At this rate, the savings would be $ 32.50 per household. Additional lamp costs would remain $5.36 per year. Considering the 11 million electrified households, the net benefit to residential users nation-wide would be $ (32.50 – 5.36) x 11 million, almost **$ 300 million a year.**

ECONOMIC IMPACT ON THE ELECTRICITY DISTRIBUTION COMPANY

Lamp replacement reduces revenues, but also reduces energy purchases, system losses, and investment requirements for system expansion. According to a simulation model developed by Edenor, the energy savings and power reduction values measured and reported here would result in a marginal loss to the company. The magnitude of the loss is a small difference between large numbers. The value is quite sensitive to the hourly distribution of load. In our measurements (which correspond to holiday periods) there was considerable light use (and savings) in the valley period (11 PM to 5 AM). Under more typical operating conditions light use in this period would be less, and the model suggests that lamp replacement may lead to a slight marginal gains.

We should keep in mind that residential electricity tariffs in Edenor's service area are relatively low. Thus, in some parts of the country, lamp replacement might lead to revenue decreases significantly in excess of corresponding cost reductions.

Thus distribution companies in Argentina are likely to be indifferent to, or reduce their marginal profits, as a result of a large-scale promotion of CFLs. It should be pointed out that profits would never decrease since energy consumption has been increasing steadily and even the most successful promotion of energy efficiency is unlikely to reduce sales or profits.

We have seen that users have potentially much to gain through increased energy efficiency. The society as a whole can offset the expansion of electricity generation, transmission and distribution, and save fuel, with significant economic and environmental benefits.

Distribution companies currently have no incentive to promote energy efficiency or load management. Tariff structures may be designed to provide such incentives. One way would be to determine efficiency levels of lighting (and other end-uses) periodically through surveys and measurements in a sample of houses. Then tariffs would be increased depending on efficiency improvements actually achieved. The principal disadvantage to this approach is that the statistically significant determination of small efficiency improvements will require a large sample size and will be very expensive.

An alternative incentive program for the distribution companies considers that the administrative costs of a DSM program are far higher than the values involved in potential reductions in marginal profits. Program costs increase if subsidies are added to promote energy efficiency. In many countries, distribution companies are compensated for administrative and subsidy costs of specific DSM programs, designed with the participation of the distribution company, the regulatory agency and appropriate consumer protection and environmental NGOs.

We believe such an approach should be undertaken in Argentina prior to the tariff reforms scheduled for 2002.

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