HOURLY DEMAND CURVES FOR RESIDENTIAL END-USES IN ARGENTINA AND POTENTIAL FOR LOAD MANAGEMENT

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SUMMARY

Measurements, surveys and billing data analysis in a sample of Buenos Aires households were used to estimate principal residential end uses of electricity, and corresponding hourly load shapes. Lights, refrigerators and video appliances add up to over 75% of total electricity use. The demand for lights and video appliances coincides strongly with household and system power demand periods. Peak demand may be decreased significantly through efficiency improvement for lights and video appliances. Electricity distribution companies may promote such measures, if tariff structures are adequately designed.

INTRODUCTION

Reliable, quantitative information on energy consumption and time dependence of power demand curves for electricity end-users can be used to determine current and future requirements for power plants, as well as transmission and distribution systems. It has also increasingly become evident that these requirements can be reduced, and the costs of providing electricity brought down, through measures that reduce demand through improved efficiency of electricity use and load management at the user level.

Energy consumption data by energy-use *sector* are generally available from national statistical and energy agencies. Electric companies usually collect data on energy consumption patterns at the *end-user* level. These data are generally adequate for planning system expansion in the absence of energy conservation and load management (ECLM) programs.

Since ECLM measures are generally applied for specific electricity end-uses, the design of appropriate ECLM programs requires additional and more detailed data on the energy and power consumption patterns at the level of individual *end-uses*.

The differences in the terms *energy use sector*, *end-user* and *end-use* are illustrated in Table 1.

No reliable data on the energy consumption and power demand patterns of electricity end-uses were available in Argentina until the mid-1990s. Our group initiated the first attempts in 1994, and our estimates for the residential sector have been progressively refined.

Table 1. Energy use sectors, classes of end-users and principal end-uses of electricity

Energy use sector	End-user	End-uses
Industry	Industrial plant	Pumping
		Electrolysis
		Lighting
		Other...
Commercial and public buildings	Office building, hospital, hotel, restaurant, shopping centre, school, etc.	Lighting
		Ventilation
		Air conditioning
		Elevators
		Other...
Residential	House or apartment	Lighting
		Refrigeration
		Television and video
		Space heating
		Air conditioning
		Clothes washing
		Audio equipment
		Other...

In this paper we first summarise our estimates of energy consumption for the principal residential end-uses in Buenos Aires households. There is little seasonal variation in electricity use. Thus *hourly* variation in demand is most relevant for load management purposes. We present the methodology we used and our first estimates of the hourly load curves for the three principal electricity end-uses in Buenos Aires households.

ENERGY CONSUMPTION PATTERNS

Residential electricity end-use components for a sample of households in Buenos Aires were quantified using a combination of measurement, surveys and billing data analysis.

Measurements included both energy consumption as well as other electric parameters. Energy-use measurements consisted of monitoring household energy consumption using the utility billing meter while a similar meter was used to record refrigerator electricity consumption. The measurements were conducted during two 15-day periods for each household, once during summer and once during winter, and were used to estimate the annual energy consumption of the refrigerator.

For other electrical equipment we measured active power, current, and power factor, paying special attention to small loads sometimes referred to as “leaking electricity”: permanent and standby power input of transformers, power supplies, TVs, VCRs, hi-fis, telephones and answering machines, clock radios, PCs, etc.

The energy consumption of all equipment except refrigerators was estimated from questionnaire-based surveys of hours of usage pattern and measured power input. Both usage pattern and power input are differentiated by type of use: operating, active and passive standby, where appropriate. Lighting power input was estimated from lamp power ratings and estimated losses for fluorescent lamp ballasts.

Total household energy consumption estimated by the above “bottom-up” procedure was compared to the billing data from the previous two years. The “bottom-up” estimates were adjusted, if a large discrepancy was found in total energy consumption. Moreover, electricity used for space heating and cooling —not covered in our estimates— were determined from seasonal variations in billed electricity consumption over the two-year period.

A breakdown of the energy consumption for the principal electricity end-uses in Buenos Aires households is shown in Figure 1. Each bar shows the average consumption for a specific end-use as a percentage of household total.

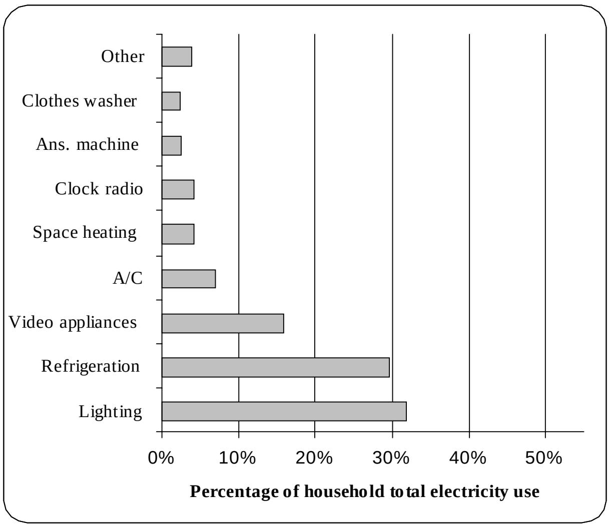

Fig. 1. Contribution of major residential electricity uses in Buenos Aires to total household energy consumption [1].

It should be pointed out that the number of households in the sample is small, so that the figures are approximate. Nevertheless, the principal conclusions are clear: the three principal end-uses are lights, refrigerators, and visual entertainment devices (TVs, VCRs, etc.) and add up to about 78% of total household electricity use. The absolute and relative contribution of the *remaining* end-uses are likely to vary as we expand the sample size but we expect that the three principal end-uses will continue to represent at least 75% of the total, and it is to these end-uses that we limit our discussion for the remainder of this paper.

HOURLY LOAD CURVES

As we have mentioned earlier, hourly variations in power demand are more important in Argentina than seasonal variations, both in the household sector, that is the subject of our study, as well as in other sectors. This is true not only in Buenos Aires but almost everywhere in the country, because Argentina has an extensive natural gas network and electricity is used little for space (or water) heating. Moreover, the saturation of air conditioners in the residential sector is relatively low, so far. In the Buenos Aires area, indeed the consumption is somewhat higher in the winter, which could be the result of higher energy use for lighting, as well as the use of portable electric-resistance space heaters.

For these reasons, we initiated our analysis of load demand curves with a study of *hourly* demand patterns for the three principal end-uses in the residential sector: lighting, refrigeration, and video appliances.

The method used was based on:
a) a questionnaire-based survey of the operating hours for lights and video appliances;
b) measured power input of video appliances in different operating modes;
c) measured refrigerator energy use; and
d) a model for hourly variation of demand for refrigerators.

One difficulty in our analysis was that the questionnaire survey of lights and video appliances were conducted by two different student groups in different sets of households [2, 3]. In each case, they had billing data on the total energy consumption of each household, so that the end-use that was analysed could be compared to the total. However, the sample sizes were small and the average consumption of the two groups of houses differed substantially from the average consumption for Buenos Aires. The “lights” households had an average consumption of 2485 kWh/year, while the “video-appliance” households averaged 2112 kWh/year, against a utility-wide average residential consumption of 1835 kWh/year during the survey period (1996-97). To partially compensate for these differences, the consumption patterns for the surveys were pro-rated to a total household energy consumption of 1835 kWh/year.

For refrigerators, we considered an average consumption of 650 kWh/year, based on previous measurements. For hourly time variation in electricity demand, we observed, from data based on extensive monitoring of refrigerators in the USA [Dutt et al., 1994], that consumption variation over a day was approximately sinusoidal. The diversified power input of refrigerators has a minimum at 6 AM and a peak demand at 6 PM that is 40% higher than the minimum. This variation corresponds to the following relationship:

$$A(t) = A_0 \times (1 + 0.16\ sin\,\omega\ t) \qquad (1)$$

We assumed that the remaining electricity uses added up to 15% of the total (1835 kW/year), and that this demand had no hourly variation.

Figure 2 shows the resulting hourly demand pattern for Buenos Aires households, broken down among the three main end-uses and “other”.

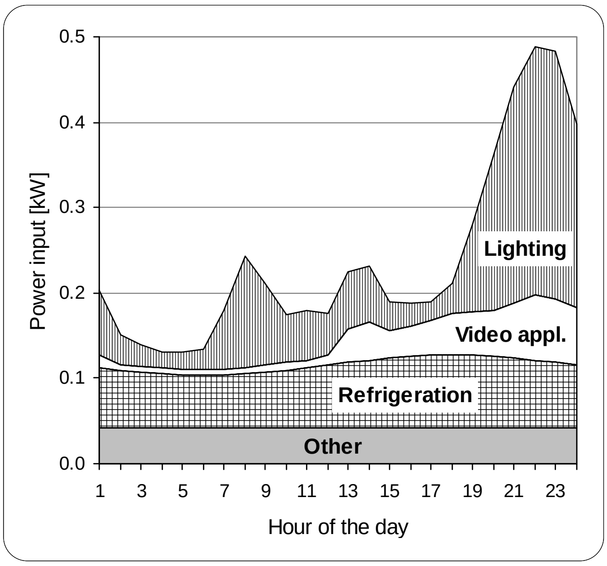

Fig. 2. Hourly load curve for major end-uses in Buenos Aires households

Since we have chosen to ignore seasonal variation in demand in the current study, the hourly load shape in Fig. 2 is intended to represent an annual average.

The sum of the hourly loads over the 24-hour period, multiplied by 365 yields estimates of annual energy consumption for the different end-uses considered. The results are shown in Table 2.

Table 2. Annual energy use, estimated from load shapes

End-use	**Annual use, kWh (%)**
Lighting	818 (39%)
Refrigerators	650 (31%)
TV y video	266 (13%)
Standby, except TV & video	88 (4%)
Other	275 (13%)
Total	**2097 (100%)**

The most significant result of this exercise is that the total energy use, 2097 kWh/year, is significantly higher than the average for Buenos Aires households (1835 kWh/year) considered here. The discrepancy is all the more remarkable since we adjusted the total consumption of each sample to this overall consumption value in obtaining load curve estimates. The principal reason is that in the houses of the lighting survey, this end-use was so large a part of total energy use that even when the total was scaled down to 1835 kWh/year, the lighting consumption added up to 818 kWh/year, the value shown in Table2. Similarly, the video appliances consumed a larger fraction of total consumption in the houses where this equipment was surveyed, giving the larger absolute value shown in Table 2. Together with fixed estimates for refrigerator energy consumption and for other end-uses, total consumption adds up to 2097 kWh/year, some 14% larger than the utility average of 1835 kWh/year.

To look for clues to the discrepancy, we compare the percentages in Table 2 to the values we had obtained in our earlier studies and shown in Fig. 1. There we had estimated lighting energy consumption to be 32% as compared to 39% in Table 2. (Video appliances were estimated to consume 16% of the total in Fig. 1 and 13% in Table 2; the absolute value of this difference is small and probably not significant considering the small sample sizes.)

One reason for a larger consumption estimate in the lighting survey is that it was conducted during July (winter in the Southern Hemisphere), and it is likely that respondents reported the longer operating hours that would correspond to the season.

Another reason for an overestimated annual energy consumption is that people would report operating hours for lights (and other equipment) when they are normally home. Since they are not home all days of the year —because of holidays, out-of-town visits, etc.— the annual consumption would be less than 365 times the reported daily load. Part day absences would alter the daily load curve as well as reduce overall energy consumption.

The results presented are the first estimates in Argentina of hourly variation in residential demand, disaggregated by major end-use categories. Improved estimates would require the following steps:

a) use of much larger sample sizes, segmented by socio-economic group;
b) surveys of all end-uses in the same set of households to avoid biases in the relative magnitudes of different end-uses; and
c) lighting surveys in different seasons to estimate variations over the course of the year.

In a subset of the larger sample, the following steps should also be undertaken:

d) monitor refrigerator load curves in different seasons;
e) monitor light and video appliance consumption pattern using loggers and comparing the results with survey data.

POTENTIAL FOR LOAD MANAGEMENT

Our measurements confirm that residential lighting and video appliances strongly coincide with the overall peak load, not only for this sector but for the Argentine power system overall. Fig. 3 shows a typical load curve for the Argentine interconnected grid.

Improvements in the energy efficiency of residential lighting and video equipment will have a significant and favourable impact on the load shape, reducing demand during the evening peak period. We quantify the impact on load shape using the following procedure.

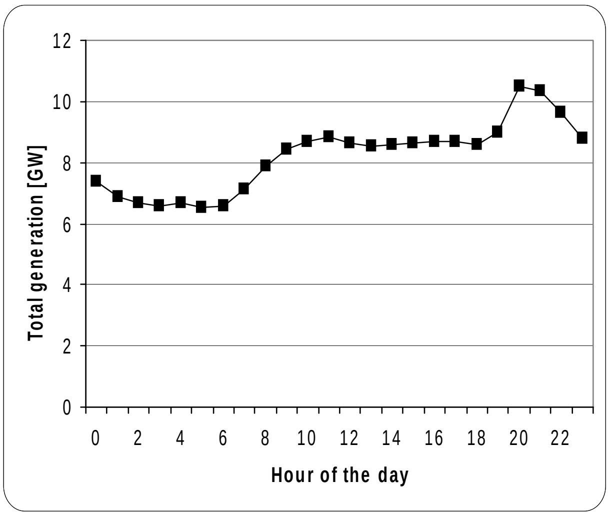

Fig. 3. Hourly variation of electricity *generation* in the wholesale market on a typical weekday in Nov. 1998 [5].

Lighting

We consider the replacement of incandescent lamps with compact fluorescent lamps (CFLs) whenever the latter is cost effective. We use *annualised lifecycle cost* as the criterion for determining cost effectiveness. The annualised lifecycle cost (ALC) of purchasing and operating a lamp is given by:

$$ALC = C \times CRF(d, n) + PE \times E \qquad (2)$$

where C is lamp cost ($), E is the annual energy use (kWh/year) and PE is the energy price ($/kWh). CRF is the capital recovery factor that relates an investment, such as lamp purchase, to an annual equivalent value. CRF depends on lamp life (n, years) and discount rate (d, per year) used and is given by:

$$CRF = \frac{d\,(1+d)^n}{(1+d)^n - 1} \qquad (3)$$

Since lamp life is generally rated in hours of operating time, whereas for financial purposes, the appropriate lifetime is the time elapsed, n years, which depends on hours of lamp use per day. We assume a life of 1000 hours for incandesent lamps and 8000 h for compact fluorescents. (The latter figure is lower than the manufacturer-rated value of 10000 hours, to account for the shorter operating cycles in our case.) We consider PE = 0.10 $/kWh and a real discount rate of 0.09 per year. Other assumptions are summarised in Table 3, which also lists minimum lamp use for which replacing an incandescent with a CFL would be cost effective.

From the lighting survey we can calculate the hours-per-day of use for *each* incandescent lamp in our sample, and determine whether it is cost effective to replace that lamp. Since the survey data were available on an electronic spreadsheet, the otherwise cumbersome calculation was performed automatically. The lighting energy savings potential for the surveyed households average 52% for our assumptions. Moreover, energy consumption is concentrated in a few lamps in each household, so that 45% of the energy savings potential requires replacement of only two lamps per household [6].

Table 3. Replacement of incandescent lamps by CFLs. Technical characteristics and minimum hours of daily use to make replacement cost effective [2]

Incand. Lamp power [W]	25	40	60	75	100
Luminous flux [lm]	230	430	730	950	1380
Lamp cost [$]	0,50	0,40	0,55	0,55	0,70
CFL lamp power [W]	7	11	15	20	23
Luminous flux [lm]	300	600	900	1200	1500
Lamp cost [$]	21	21	22	23	24
Min. use for cost effective replacement [hours/day]	3	2	1,5	1,5	1

Video appliances

Television sets, videocassette recorders and players, and cable converter boxes make up this category. This is the third largest electricity end-use category in Buenos Aires households. Their use is concentrated in the afternoon and evening hours, with even stronger coincidence with sector and system peak demand than lighting. However, few countries give importance to this equipment, which is designed, licensed for manufacture, manufactured and sold in a globalised marketplace. Energy efficiency improvements would require coordination among the companies and nations that define the technologies that reach households in Argentina and most other countries.

To estimate energy and power savings in TVs and VCRs (which add up to most of the energy use in this appliance group), we considered that all TVs and VCRs are replaced by the most efficient models in their category, considering the size of TV screens. For the efficient TVs and VCRs we assume a standby power input of 3 W.

We do not know with precision what the additional costs would be for improving the energy efficiency of TVs and VCRs. However, two observations are pertinent:

a) there appears to be no correlation between appliance cost and energy consumption and
b) the additional appliance cost that may be economically justified *per watt* of reduction in power input is relatively large, for standby and “On” operation of both TVs and VCRs.

For these reasons, we believe that the additional investment in going from the average model in use to the most efficient is highly cost effective. Indeed, by limiting ourselves to the most efficient models of our survey, our estimates of potential savings are conservative: we do not consider more efficient models that are available. The technical and economic potential for savings is much higher, if we consider new technologies [7].

Refrigerators

Refrigerators have little variation in power input, mostly reflecting variations in kitchen temperature and door openings. The kitchen is hotter and there are more door openings during the early evening hours, which coincides with system peak loads. (Also consumption is higher in summer.) One way for altering fridge operation for load management consists of storing cold within the appliance to greatly reduce power input during peak demand periods. Fridge power demand would thus be shifted to off-peak periods.

While this idea was proposed at least 20 years ago [8] no residential refrigerator with significant load shifting capabilities is known to exist on the market. There are several practical difficulties. Most appliances in this category have compartments at two or more different temperature. So cold must be stored at different temperatures, or else temperatures of the different compartments cannot be maintained stable. In principle, for (deep) freezers, cold could be stored at a temperature lower than the thermostat setpoint without affecting food quality. Even in this case, however, effective cold storage would require that part of the interior volume be used for this purpose, an inconvenience that may discourage potential users.

Parts of Brazil suffers from a sharp early evening system peak, when the end of the office building load coincides with the start of the residential and street lighting demand. At least one electric utility —CEB, serving Brasilia— has tried to shut down fridges for an hour to reduce the short-term peak. Besides many difficulties in implementing the program, they recorded little reduction in peak demand [9].

In Argentina, the evening peak is much more extended, so that effective management cannot be limited to shutting off fridge power input for a short time. Rather, enough cold must be stored to move the peak power input from 6 PM to past 11 PM, resisting many door openings in the interval. This appears to be a tall order... While it might be easier to store cold in freezers, the number of hours of load shifting required, and the low saturation of freezers in Argentina, suggests that this option is unlikely to be pursued.

Thus, we believe that the practical potential for demand shifting through storage of cold in refrigerators and freezers in Argentina to be insignificant.

Peak demand reduction

We consider a hypothetical substitution of all eligible incandescent lamps with equivalent compact fluorescent ones (whenever cost effective), and of all TVs and VCRs with the most efficient models in their class. This substitution represents an "instantaneous" or "overnight" potential for load management through energy efficiency improvements. A more reasonable estimate of the potential for energy savings and load management would involve a gradual replacement of lamps, and the purchase of efficient video appliances, instead of average models, against a backdrop of increased demand for lights and appliances, as a consequence of an increase in the number of households, more lamps per household, and an increased saturation of appliances. Nevertheless the "overnight" substitution is a simple way of visualising the potential for load management and is shown in Figure 4.

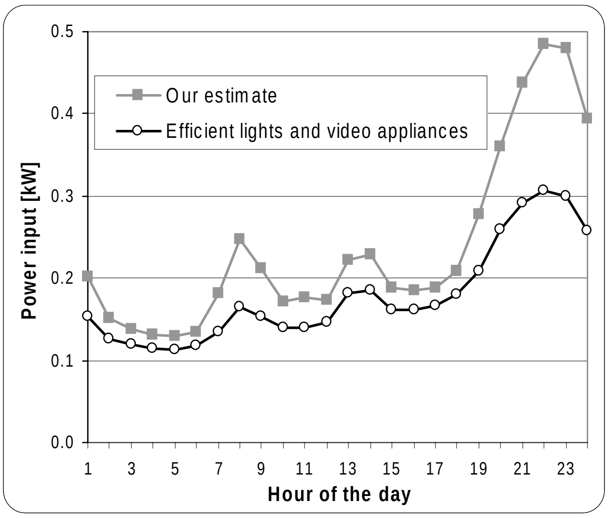

Figure 4. Our estimate of total household demand compared with a scenario where lights and video appliances are efficient. The difference shows the potential for load management.

Because of the significant contribution of lights and video appliances to peak demand, the potential for reduction in load management from these energy efficiency measures is large: maximum demand would fall from 0.49 kW to 0.31 kW per household. As mentioned above, we suspect that our surveys overestimated lighting energy use. Thus, the actual potential for peak demand reduction is likely to be somewhat less than that suggested by Fig. 4.

PROMOTING ENERGY CONSERVATION AND LOAD MANAGEMENT

Manufacturers of efficient equipment and other market players promote some ECLM but this leaves a significant potential untapped. What part of the potential for energy savings and load management that can actually be obtained depends on the nature and effectiveness of energy conservation and load management (ECLM) programs. Such programs may be determined by government policy and action, as well as the activities of electricity companies. The participation of the latter in promoting ECLM is generally referred to as Demand-Side Management (DSM).

In a deregulated market such as Argentina, generating companies compete with one another to provide electricity to a wholesale market. Transmission companies get paid for wheeling power from generators to purchasers. Distribution companies, large users, and power marketers purchase electricity from the wholesale market for their own use or for resale.

In a previous paper we identified the distribution companies (Disco) as best suited to provide DSM services to their residential customers [10]. They may do so in their own financial interest. An increasing electricity demand increases their revenue but may also require them to invest in increasing distribution system capacity. Their benefit cost ratio (BCR) for different types of demand increase is given by the following equation [10]:

$$BCR = \frac{AH \times \left(TAR - SMP/\left(1 - DL\right)\right) \times PF}{PCF \times UIE \times CRF\left(d, N\right)} \quad (4)$$

where *TAR* is the electricity tariff ($/kWh), *SMP* is the Disco's purchase price of electricity in the spot market ($/kWh), *DL* represents the distribution losses (fraction), *AH* is the number of annual operating hours of the increased demand, *PCF* is the peak coincidence factor of the demand and *PF* is its power factor, *UIE* is the unit investment for (distribution system) expansion ($/kVA), and *CRF* is the capital recovery factor, as in Eq. (3).

For residential customers who pay for energy use but not peak power demand, the Disco loses money when:

- the demand increase is for short periods of time coinciding with the system peak; here AH is low, PCF and SMP are higher,
- TAR is low, and/or
- UIE is high.

For conditions prevailing in Buenos Aires, Discos would stand to gain financially only by promoting efficient lamps to one of the two tariff classes (R2), which corresponds to bimonthly household energy use higher than 300 kWh. Energy conservation measures that reduce base load demand as well, such as efficient refrigerators, would significantly reduce Disco profits.

What is required is a tariff and regulatory structure whereby Disco revenues are related not just to their sales volume but includes the efficiency of use on the customer side of the meter as well. In this way, the financial interests of the Disco and their customers are not opposed, and the economic benefits of ECLM would be shared by both. With a financial stake, Discos can go a long way to promote energy conservation and load management among their residential and other customers.

Specifically, high first costs and uncertainty about product quality are major barriers to the use of compact fluorescent lamps. A Disco could bulk purchase CFLs that meet verified quality standards, and finance their sale to their customers, with repayment through the electric bill at reasonable interest rates, resolving all the barriers.

In the case of video appliances and refrigerators, where efficient products are generally not available in Argentina, the involvement of several large Discos could create a significant market demand for such products, and make them accessible to potential consumers.

Thus, we believe that there is a significant potential for energy efficiency improvement and load management in the residential sector that can be promoted through the participation of distribution companies, provided the regulatory structure gives them a financial stake in the process.

REFERENCES

[1] C.G. Tanides, "Uso eficiente de la energía eléctrica en el sector residencial argentino: estado actual y posibilidades futuras", *Proc. ASADES 1997*, Asociación Argentina de Energía Solar, vol. 1, pp. 97-100.

[2] L. Mazzeo, F. Bertolotti, and E. Wada, "Estimación del consumo de energía en la iluminación residencial", student research paper for the course *Uso Eficiente de la Energía Eléctrica*, Dept. of Electrotechnologies, School of Engineering, Univ. of Buenos Aires, 1997.

[3] E. Barrio, L.R. Quintanilla, and C. Recchia, "Estimación del consumo de energía y potencial de ahorro en equipos de televisión y video del sector residencial", student research paper for the course *Uso Eficiente de la Energía Eléctrica*, Dept. of Electrotechnology, School of Engineering, Univ. of Buenos Aires, 1997.

[4] G.S. Dutt, J. Proctor, et al., "Large-scale residential refrigerator field metering", *Proc. 1994 ACEEE Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington D.C., pp. 2.77-2.86.

[5] CAMMESA, *Boletín del MEM No. 34*, Compañía Administradora del Mercado Mayorista Eléctrico, Dec. 1998, p. 4.

[6] C.G. Tanides, "Uso eficiente de la energía eléctrica en la iluminación residencial", *Proc. ASADES 1998*, vol. 2, pp. 6.5-6.8.

[7] A. Meier, W. Huber and K. Rosen, "Reducing leaking electricity to 1 watt", *Proc. 1998 ACEEE Summer Study on Energy Efficiency in Buildings,* pp. 1.185-1.196.

[8] J. Beyea, a researcher at Princeton University Center for Energy and Environmental Studies proposed making ice within refrigerators during off-peak hours for peak-load management, 1977.

[9] F. Figuereido, CEB (Brasilia Electric Company), *pers. comm.*, 1998.

[10] G.S. Dutt, C.G. Tanides and M. Brugnoni "DSM (Demand-Side Management) & distribution companies in deregulated markets: possibilities for Argentina", *Proc. Int. Congress on Electricity Distribution Systems (CIRED Argentina '96)*, pp. 7.47-7.46.

Hourly demand curves for residential end-uses in Argentina and potential for load management

Gautam S. Dutt , Carlos G. Tanides

The three principal end-uses of electricity in Argentine households, adding up to about 75% of energy use, are (a) lights, (b) refrigerators and freezers, and (c) TV sets and associated equipment (video and cable). The hourly demand pattern of these end-uses was determined from surveys and measurements in a sample of households. The diversified peak power of lights and TV sets amounts to 0.4 and 0.8 of installed demand for these end-uses, respectively.

The replacement of incandescent lamps with compact fluorescent lamps and the gradual incorporation of more efficient TV sets offer significant potential for reducing demand during peak periods. We quantify the potential for load management for these options Another possibility, though requiring technology development, would be to increase the thermal inertia of refrigerators and freezers so that they may be turned off during peak periods. We also make some preliminary estimates for peak load reduction for this alternative.

Electricity purchase price of the distribution company is different for peak, valley and shoulder periods (currently 22.30, 13.60 and 21.30 US$/MWh respectively). Moreover, the company needs to invest in equipment to meet maximum *power* demand, while their revenues to residential customers depend exclusively on *energy* sales independent of time of use. Hence, distribution companies stand to gain financially by reducing peak demand (efficient lights and TV sets) or by shifting demand to off-peak periods (refrigerators and freezers).

One electricity distribution company of Buenos Aires is currently developing a program to finance compact fluorescent lamps (CFLs) to their residential customers, with repayment of the lamp cost over time through the electric bill. Other mechanisms by which electricity distribution companies may promote load management alternatives for other residential end-uses within the context of the Argentine electricity market are also discussed.