Evaluation of a Residential Base Load Monitoring and Management System

Prepared by: Toronto and Region Conservation

Final Report

EVALUATION OF A RESIDENTIAL BASE LOAD MONITORING AND MANAGEMENT SYSTEM

Final Report

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Toronto and Region Conservation Authority's
Sustainable Technologies Evaluation Program

For:

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program was developed to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing technologies;
- develop tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical products or devices; they may also include preventative measures, alternative service delivery approaches, and other innovate practices that help create more sustainable and liveable communities.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

New time of use electricity rates, rising costs and interest in shifting electricity use to off peak periods are driving the need for better control of electrical base loads in Canadian homes. Several commercial home energy monitors are now available to help reduce these loads by providing information to homeowners on their energy use through two-way communications enabled receptacles, switches or circuits. The dx2 home energy management system takes this technology one step further by providing both user feedback and the ability to actively control electrical loads. This study evaluates the effectiveness of the dx2 system to reduce energy, shift loads to off-peak times, and optimize the operation of base loads for cost savings to the homeowner.

The dx2 system provides energy use feedback and electrical load control functionality through the use of software, a user friendly interface, SMART receptacles (safe plugs) and light switches (Figure 1). Individual electrical loads are configured according to user based preferences for an *at home* setting, an *away* setting and a *sleep* setting. The system can be controlled remotely by computer, via a smart phone, or if desired, by a utility to reduce peak demand.

The dx2 system evaluated in this study was installed in the Archetype Sustainable House owned and operated by the Toronto and Region Conservation Authority. This demonstration home contains several innovative residential green building technologies, a comprehensive energy monitoring and data acquisition system, as well as the dx2 home energy management and control system.

In this study, electrical loads were automated to simulate a typical residential electricity load profile. Three scenarios were monitored to assess the potential benefit of the system both from a cost and energy savings perspective. The first scenario is a worst case, assuming no energy savings control either by the homeowners or via an automated system such as dx2. The second scenario assessed energy savings with automated controls for an *at home* and *away* setting. The final scenario adds *sleep* modes to generate greater energy savings.

Results of this study show energy reductions and cost savings from load shifting, control of phantom loads and, more significantly, from the control of individual plug loads (Figure 2). Phantom loads were reduced by 60% under the test scenarios, with costs falling from $37 to $15. Reducing the operation of select base loads in the form of plug and exterior lighting (135 watts) showed annual savings of approximately $64 between the highest and lowest energy use scenarios tested. If these energy savings are applied on a scale of 500 homes over the course of a year, the net reduction is 406 MWh. Based on an annual, medium home use energy profile reported by Armstrong et al (2009), the net energy savings would be sufficient to power an additional 50 homes.

Significant potential savings were also available to homeowners when the system was used to control hard wired lighting. The annual cost savings between a scenario with most lights on all the time ($985), and the same lights turned off during the day and during sleep times ($324) was $662. While it is unlikely that homeowners would leave lights on when they leave the house or go to bed at night, the lights on all the time scenario offers important insight as a comparative reference point to the application of system modes and their associated cost savings with regards to hard wired lighting.

In addition to cost savings, benefits of this home energy management system also include control of electrical loads from a convenient, centralized and/or remote location, and safety features such as protection from under/over voltage conditions; surge, arc fault, and lightning protection; and home security features. Although the value of these features was not specifically evaluated in this study, these are clearly important selling features of the system as a whole.

This study documents successful energy management control, and reviews potential for load reductions and cost savings associated with the application of various control strategies. Recommendations are provided for product development and future research needs associated with the evaluation and practical application of the technology for controlling electrical loads and home energy scenarios not addressed in this study.

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1.0 BACKGROUND AND STUDY PURPOSE

New time of use rates, increasing costs and desire to shed and shift electricity use to off peak periods are driving the need for better control of electrical base loads[1] in Canadian homes. Reductions in base load electricity use will also have a dramatic effect on the cost to build net-zero energy homes. Since every watt of electricity use in the home needs to be offset by renewable power production generated on site, reductions in base loads mean less renewable energy capacity needs to be specified in the design of the home. Further, external decision-making factors such as carbon content of the electrical grid, the instigation of a demand/response peak saver event from a Local Distribution Company (LDC), or forecasted weather could come into play in deciding how systems will be operated.

Homes equipped with innovative, two-way communications enabled receptacles, switches or circuits will assist in meeting these objectives. Several commercially available home energy monitors are available to help homeowners better understand their power use. What is missing is an energy management device that bridges the gap between informing homeowners of their energy consumption and facilitating optimum control of these devices based on opportunities for energy savings afforded by an active Home Energy Management System.

The Archetype Sustainable House, owned and operated by the Toronto and Region Conservation Authority, is a demonstration home containing several innovative residential green building technologies. The house includes a comprehensive energy monitoring and data acquisition system as well as a home energy management and control system designed and manufactured by dx2 technologies Inc. Since the system is already installed and a partnership has been established with the system manufacturer, the site provided an ideal location for demonstration and evaluation of the energy management device.

The purpose of this project is to evaluate the capacity of the dx2 home energy monitoring and control system to control electrical loads, reduce energy use and provide savings to the homeowner. This includes assessing opportunities for peak shaving and load shifting through the use of automatic and user based controls. Recommendations on opportunities for system optimization and integration are also provided. Results are intended to be used by government agencies looking for solutions to climate change, utilities and regulatory agencies looking for electrical load shaving and peak load shifting opportunities (such as Power Stream, Toronto Hydro and the Ontario Power Authority) and agencies interested in demand side management opportunities.

[1] Base load electricity use refers to the use of electricity for all purposes other than space conditioning, and heating of domestic hot water

2.0 SYSTEM DESCRIPTION

The dx2 residential energy monitoring and control system allows the homeowner to review home energy use, actively control numerous individual electrical loads, and to program his or her electrical use to make the most of time of use pricing and save on electrical utility bills. This system is unique in that it not only displays and records collective household energy use and use from individual appliances or circuits, but most importantly it has the ability to *control* these individual appliances and circuits (Figure .2.1).

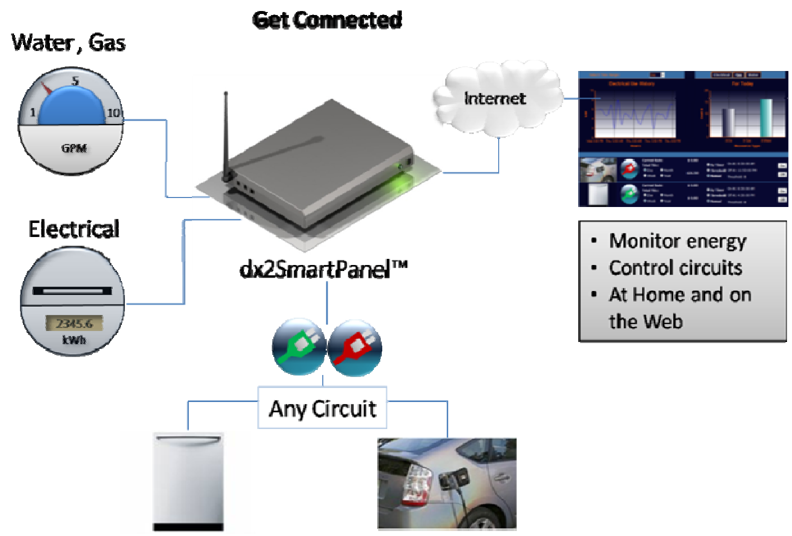

Figure 2.1: Schematic of the dx2 home energy monitoring and control system (source: dx2)

Two way communications between the receptacle, switch or circuit and the dx2 software is accomplished via a Zigbee network. This system has the ability to control electrical base and phantom loads. The system provides a central and convenient location to activate system controls, and the potential to be controlled remotely by computer or via a smart phone. It also provides home security and safety features, such as protection from under/over voltage conditions; as well as surge, arc fault, and lightning protection. It also has the potential to reduce peak demand when a demand/ response event may be issued from a utility.

The main software monitor and control interface is shown in Figure 2.2. The system is comprised of a series of SMART receptacles called Safeplugs. These receptacles communicate via a 2 way wireless communication protocol on a Zigbee network. Appliances are equipped with a Radio Frequency Identification (RFID) tag on the plug that can be read by Safeplug and the dx2 software. The user identifies the appliance to be controlled, which is then identified through the associated RFID tag. The RFID tags also provides maximum current ratings particular to the appliance, so that the receptacle will shut off when this rating is exceeded. This two way communication allows the receptacle to execute a command initiated by the software, but also to communicate power consumption back to the software.

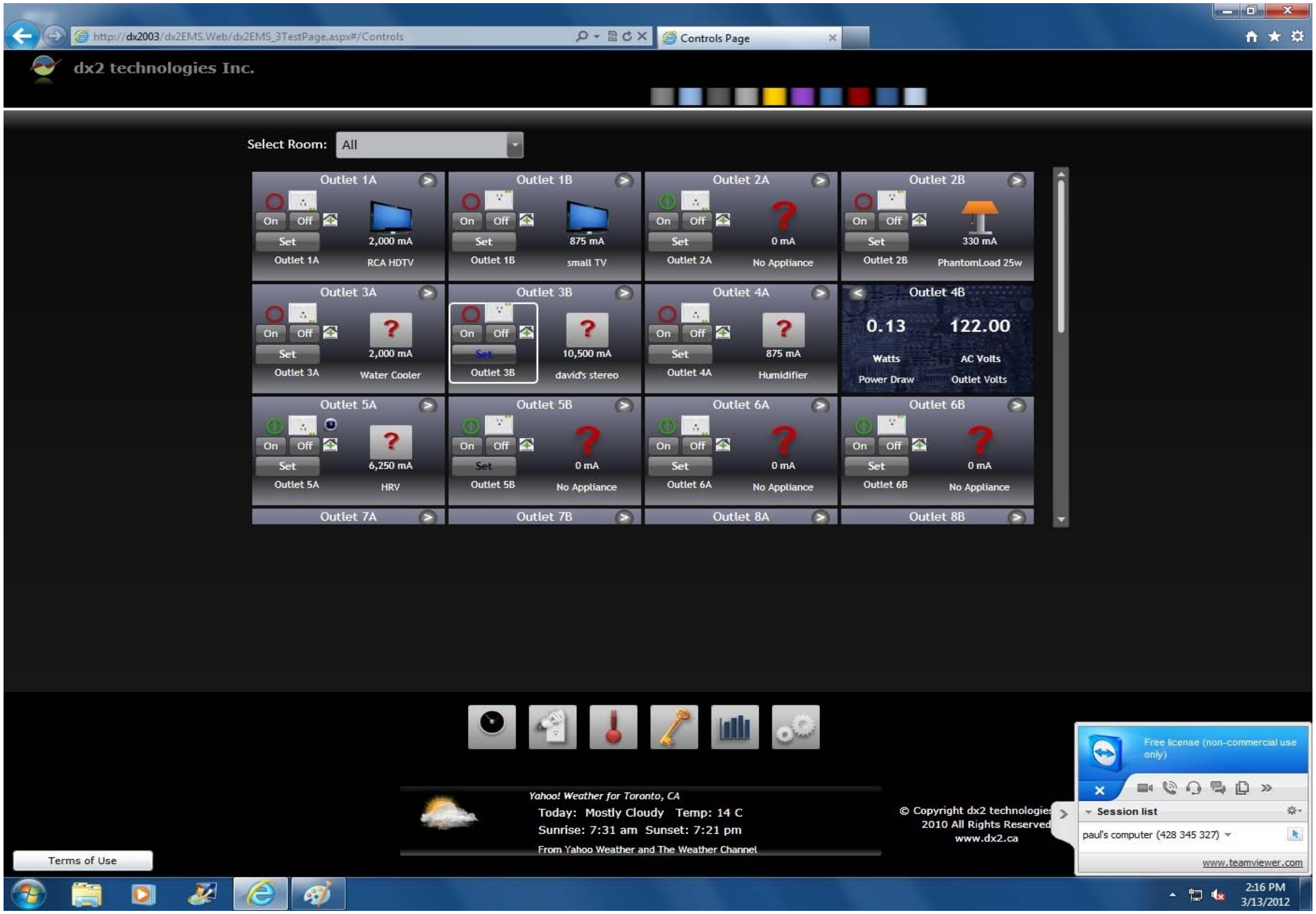

Figure 2.2: The dx2 system control interface for setting up individual appliance control. Each square shows the listed appliance, a receptacle ID, a manual on/off switch, a small arrow on the top right corner that will flip the square to show real time consumption from the individual appliance, and a set button that takes the user to a full screen of control options for the individual appliance.

A CentraLite switch was installed that controls a relay on the hard wired lighting sub panel. In the Archetype house all hard wired lighting circuits are dedicated lighting circuits. All of these lighting circuits are connected to a dedicated lighting sub panel. The mains to this panel pass through a contactor that can energize/de-energize all lighting circuits at the same time. This feature was built into the house to allow for an “all off” switch to be located by the front door. This set-up is efficient in terms of a built in “all-off” switch but does require dedicated light circuits, which is not standard practice in existing residential homes, and would have to be installed at the time of new construction.

In addition, the extra sub panel and contactor add cost to the system and residential electricians may not be familiar with wiring control circuits for the contactor. In this study, we use the wireless communication ability of the CentraLite switch to control the central contactor through the dx2 system. This demonstrates its communication and control capability but does not utilize the full capability of the product as a distributed lighting control. As a distributed type of lighting control it does not need a dedicated lighting circuit, nor does it require a dedicated lighting panel and contactor to work. At the time of implementation the Zigbee enabled switch was a “sample” for research use only and available quantities were restricted.

To fully show its capabilities the whole house could be fitted with these automated switches. In the Archetype house the exclusive use of automated light switches would make the dedicated light circuits, dedicated lighting panel, and contactor redundant. In an average home, hard wired lighting is not generally controlled in a subpanel and can occur on the same circuit as plug loads. The dx2 system provides this flexibility of control, and can be retrofitted and applied to conventional residential wiring to accomplish the same objective.

2.1 Control Logic

The Energy Saver mode is top priority in the control chain and it will override other control modes and timer settings. If a device is set to “Use Device Anytime $$$” then this control mode is ignored and the control logic check is passed to the next stage. If a device is set to “Use Device at Mid Peak $$”, and the current energy rate of the time of day is Mid or Low, the logic will pass to further processing. Otherwise the device will shut off regardless of what the timers and System Mode settings tell it to do. Likewise if the device is set to “Use Device at Low Peak $” then the device will process other logic only if the current energy rate is low peak; otherwise it will ignore other settings and shut off.

The System Mode Settings will work only if either there are no timers or the “Allow System Mode to Override Timers” is selected. By Default the Timers take priority in control. Only if you check the tiny check box “Allow System Mode to Override Timers” will the system mode work if a timer is also set. This feature was included to allow the user to easily change the behavior. For example when returning from a time away from home you may want to switch back to timer mode but retain your settings for System Mode.

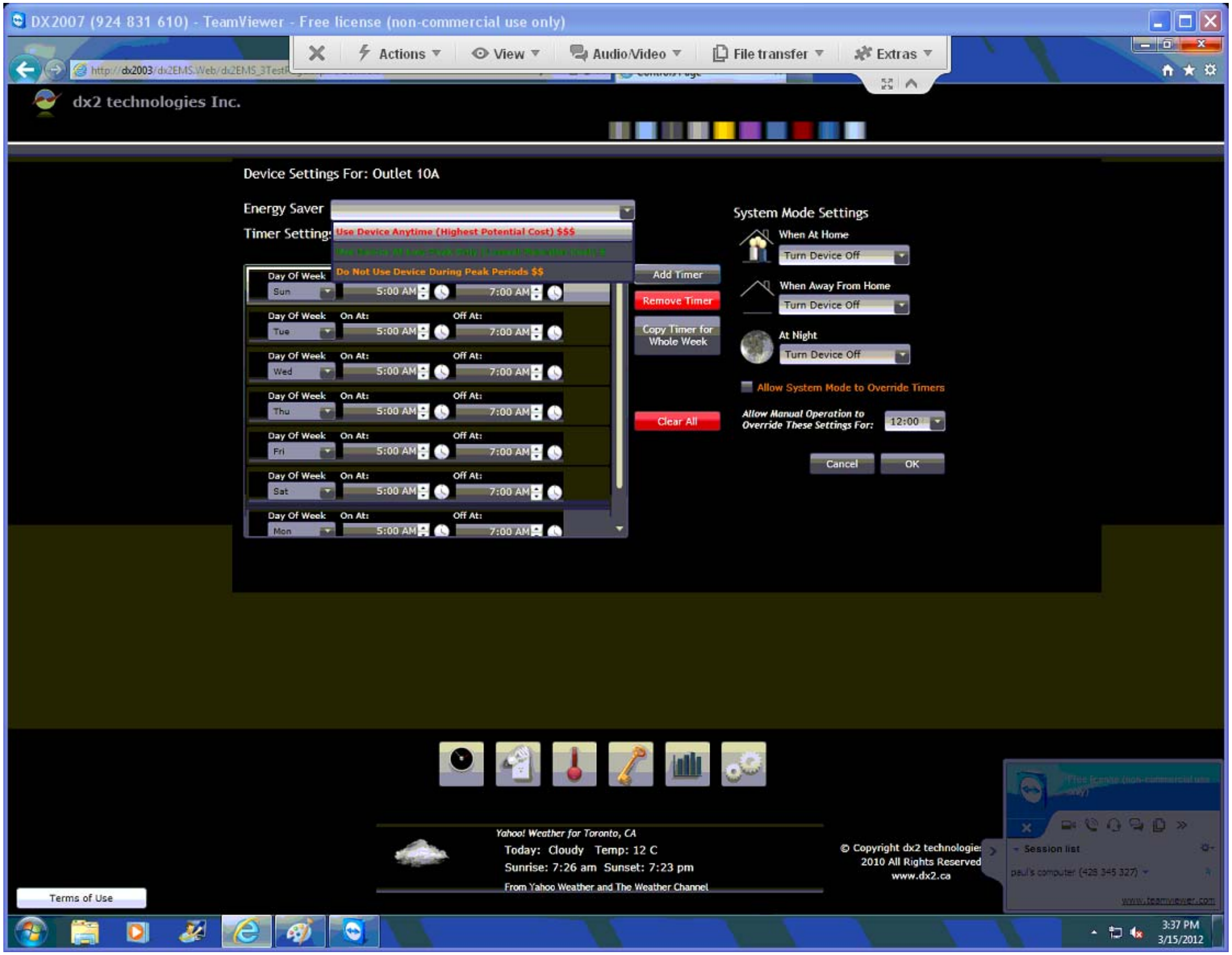

Figure 2.3: Individual appliance/receptacle control options, including System Mode Settings, Energy Saver Modes, customized timers and manual overrides. The load is identified as receptacle 10A (Block Heater) and shows the customized timer schedule from 5 am to 7 am each day.

3.0 STUDY APPROACH

The study methodology includes testing of various control options available to the homeowner through dx2 and evaluating the ability to reduce energy consumption and provide savings to the homeowner. The primary type of control in this study is a system mode controlled by the user that enables settings for each receptacle under an at home situation, an *away* setting, and a night mode (*sleep*) setting. Additional controls include an energy saver mode that sets a receptacle to be enabled: (i) all the time, (ii) during low peak only, and (iii) not at all during peak. Customized timers which allow the user to program receptacles based on half hour time slots also contribute to potential control strategies available through dx2.

Three basic scenarios were tested. The intent of the scenarios was to provide a frame of reference for the potential energy savings available in different control modes. Actual energy savings available to any particular family will depend on their specific behaviors, schedules and preferences. The three basic scenarios tested during this study were as follows:

Scenario 1: Assesses energy use without any use of energy saving controls, either instigated by users (*home and away*), or via automatic controls/shut-offs (energy saver settings). As such, this is a worst case scenario.

Scenario 2: Evaluates controls and savings through the application of *home and away* controls on the following simulated occupancy schedule: Home from 12 am to 8:45 am; Away from 8:45 am until 4:15 pm then Home again until the following morning at 8:45 am.

Scenario 3: Evaluates the *home*, *away* and *sleep* modes under the following simulated occupancy scenario. Sleep from 12 am to 7 am. Home until 8:45 am; Away until 4:15 pm; Home until 10 pm: Sleep until 7 am.

Some electrical loads were operated on different schedules to more accurately simulate how these would be controlled in a typical residential setting. These are shown in Table 3.1.

Table 3.1: Test schedules for individual appliances that deviated from the generic scenarios

Appliance	Scenario 1	Scenario 2	Scenario 3
Hard Wire Lighting	Home and Away	Home and Away	Sleep Home Away Home Sleep
Block Heater	Home and Away	Home, Away and Sleep	Custom timer only (5 to 7 am)
Fax Machine	Always On	Home and Away: On Sleep: Off	Home and Away: On Sleep: Off

The HRV, Hepa Filter and refrigerator were monitored without being actively controlled. This allows the homeowner to obtain energy use feedback and consumption data associated with the individual appliance. In these cases, the operating conditions of the appliance were not altered due to the possibility that doing so would compromise the performance of the appliance. For example, reducing the run time of appliances like the HRV or the Hepa filter would likely have impacts on the air quality within the home. Similarly, modifying the settings of the refrigerator has the potential to affect food quality if temperatures are not closely monitored and maintained. While there may be some energy savings benefit to operating these appliances outside of their normal operating conditions, evaluating and monitoring the advantages and disadvantages were beyond the scope of this study. .

3.1 Phantom Loads

In this study, the house was set up to simulate phantom loads based on estimates from previous literature. Lebot et al (2000) estimate that standby power losses are on the order of approximately 2 % of total energy use in. In Canada, Ferguson provides an estimate of 420 kWh per year while Fung et al estimated phantom losses to be slightly higher than 427 kWh or 1.17 kWh per day. Based on the average price of electricity in Ontario, ($0.081/kWh) this would cost the homeowner $34.59 every year. Phantom loads in this study used the following were set up as follows.

Table 3.2: Phantoms loads used in this study

Appliance	Phantom load
Large RCA TV	1.7 watts
Small Sharp TV	2.7 watts
Medium RCA TV	3.1 watts
Stereo	19.26 watts
25 watt bulb	25 watts
Fax Machine	1 watt
Total phantom loads	52.8 watts
Total phantom load/24 h	1266 watt hours

3.2 Time of Use Pricing

One significant factor in the rising popularity of household energy monitoring systems is the development of smart meters and time of use pricing. The Ontario Energy Board sets the price of electricity in Ontario. As of August 31st, 2011, there were about 3.1 million residential and small business customers on time of use pricing (OEB Press Release, 2011).

Time of use pricing provides an incentive to shift loads from higher priced peak to lower priced mid or off-peak periods. In this study, the following time of use rates were used to calculate load shifting opportunities based on the schedule shown in Figure 3.1 below: (i) Off-peak: 6.2 cents per kWh, (ii) Mid Peak: 9.2 cents per kWh; (iii) On-peak: 10.8 cents per kWh. For the purpose of the test, winter time of use rates and scheduling were used (November 1st to April 30th).

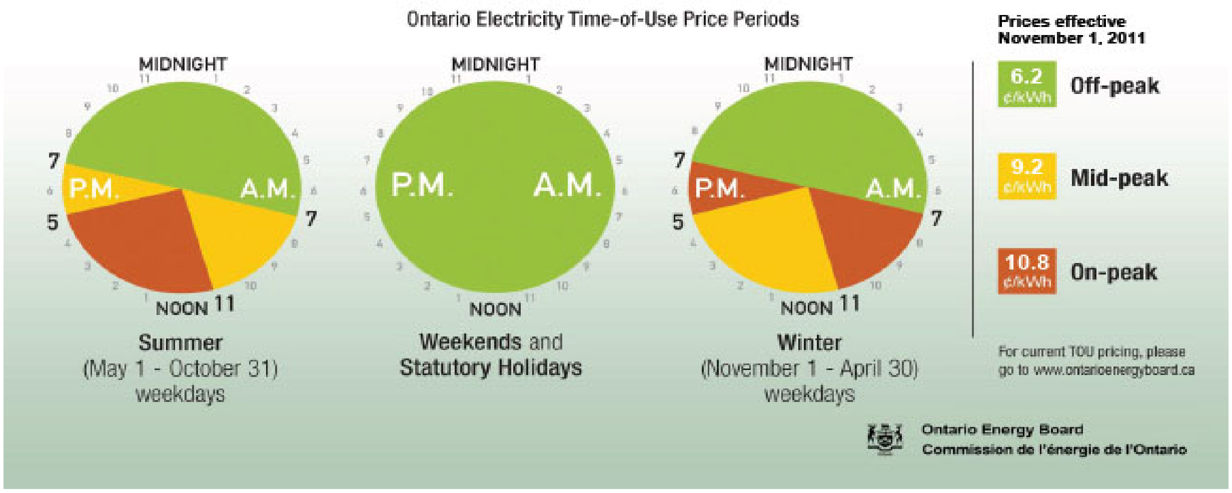

Figure 3.1: Time of use schedule and rates

4.0 STUDY FINDINGS

Energy savings from the use of dx2 controls were achieved by utilizing the three basic system mode functions. These system mode functions - the *home*, *away* and *night (sleep)* modes - allow automated control when the homeowner is at home, away or sleeping. The system settings provided energy saving opportunities by reducing individual appliance energy consumption. Numerous phantom loads were eliminated by disabling receptacles with the *away* function, and *sleep* mode, ensuring that these loads are not in operation when the house is empty and the appliance is not required.

Electricity consumption under the three system mode scenarios described in the previous section is presented in Table 4.1. As noted previously, loads for the HEPA filter, HRV, and refrigerator were not modified because to do may adversely impact the intended function of the appliances. Hard wired lighting was run in the same modes for scenarios 1 and 2, but reduced when the *sleep* mode was added in scenario 3. For the appliances listed, the overall electricity reduction from scenario 1 to scenario 2, and scenario 2 to scenario 3 was 13% and 47%, respectively.

It is important to emphasize a key operational difference with regards to different modes. As a key objective of both this study and the energy management and control system itself is a reduction of energy consumption, one of the most basic opportunities to reduce consumption and costs is to reduce the amount of time that receptacles are enabled and capable of consuming energy. In the energy baseline scenario the amount of time that most receptacles are enabled (due to the use of the anytime and always on settings) is 24 hours per day. As the study progresses to the addition of *home* and *away* settings, the total number of hours receptacles are enabled is reduced to 16.5 hours. With the addition of the *sleep* mode, most appliances consume electricity for only 7.5 hours per day. This is representative of the hours that a homeowner is likely to be at home and not sleeping. It is during this period that the household is most likely to be active and the use of appliances required. This reduction in time period that the smart receptacles are enabled has key impacts on the total household energy use. Similarly the ability to shut these loads off at critical times like morning peak and daily mid peak shuts off loads when electricity is most expensive.

Table 4.1: Electricity consumption of individual appliances under different scenarios

Appliances	Rated (Wh)	Running (Wh)	Phantom (24h Wh)	Scenario 1 Wh/24h	Scenario 2 HAH (Wh)	Scenario 3 SHAHS (Wh)
1. RCA TV	205	92	40.8	40.8	28.05	12.75
2. Sharp TV	66	39	64.8	64.8	44.5	20.25
3. 25 watt bulb phantom load	25	25.8	600	619.2	425.7	187.5
4. Water Cooler	156	153	NA	331	360	110.61
5. Stereo Power Bar	626	30.1	462	462.2	317.8	144.5
6. Humidifier	72	1	24	24	16.5	7.5
7. Hepa Filter	144	128	NA	2962	2962	3074
8. Heat Recovery Ventilator	648	396	NA	9179	9179	9179
9. Sharp Flat Screen		~ 45		1080	742.5	337.5
10. DX2 computer and power bar		~35		840	840	840
11. RCA med TV (running:1, phantom only:2,3)	168	50	74.4	1200	51.15	20.15
12. Refrigerator	852	NA	NA	900	900	900
13. Block Heater 1:H&A, 2:SHAHS, 3:timer only 5-7 am	400	390	0	6754	3000	800
14. 75 watt (exterior lighting)	75	69	0	1800	1237.5	562.5
15. Fax Machine		8	NA	192	132	60
16. 60 watt lamp – plug lighting	60	59.5	0	1440	990	450
17. Hard Wire lighting	1390	1390	NA	22952	22952	10425
Total			**1266**	**50841**	**44179**	**27131**
Total operating hours				**24 h ON**	**16.5 h ON**	**7.5 h ON**

4.1 Load Shifting

This study demonstrates the ability to shift large electrical loads to off peak periods and optimize *Time of Use* periods to benefit in the form of cost savings to the homeowner. One example of this was the load shifting of the block heater, a 400 watt load (Table 4.1). A homeowner would typically plug in the vehicle/block heater when they arrive home from work, and turn it off again at 8:45 the next morning. By applying a timer for 2 hours in the non-peak period from 5-7, energy consumption is reduced by 88%.

4.2 Base Loads and Peak Shaving

The significance of energy and costs savings across the test scenarios is well demonstrated in the costs of plug and exterior lighting. These results show the most significant cost savings of appliances under test. By reducing the run time of these base loads the homeowner stands to save almost $36 per year by utilizing the *home and away* functions, and $63 per year by utilizing the *home*, *away* and *sleep* mode functions (Figure 4.1). This is a result of general energy use reductions and the elimination of use during peak periods. In terms of overall energy savings, we can consider these examples of peak shaving to be preferred over shifting loads from peak to off peak.

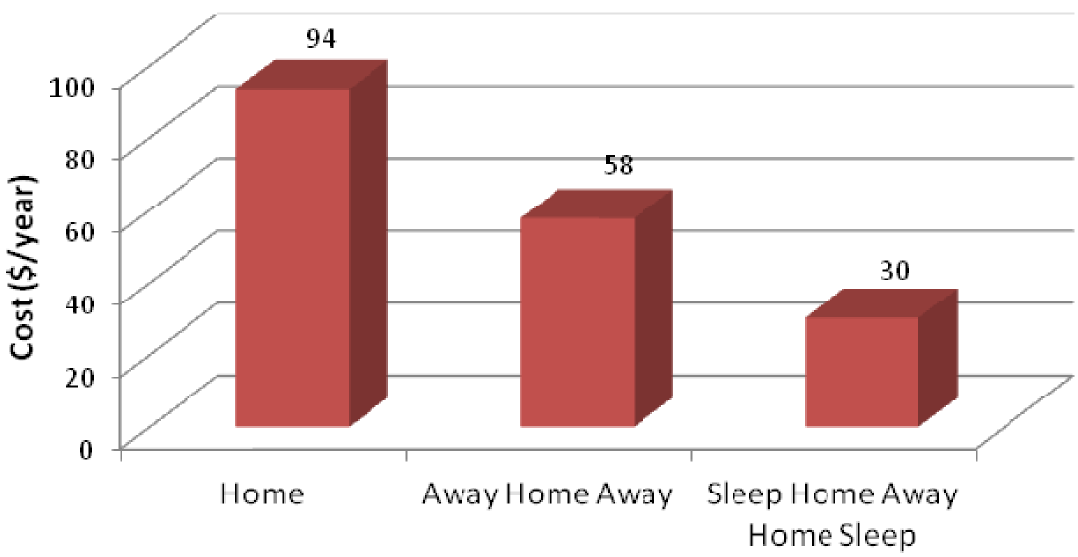

Figure 4.1: Annual cost savings associated with plug and exterior lights under three scenarios

4.3 Phantom Loads

Another opportunity for cost savings is presented by the system's ability to shut off phantom loads. While not as significant as the savings offered by switching off running base loads, over time the savings offered through the elimination of phantom loads also offers some potential. The 1266 daily watt hours of phantom load is based on research conducted by Fung et al. (2003) and is intended to be representative of an average Canadian home. The capacity to reduce phantom loads is a particularly appealing feature of the dx2 system in homes that may have a higher total amount of standby losses.

The key finding from this study with respect to phantom loads is the demonstrated ability of the system to perform this function successfully on all phantom loads. The significance of this daily consumption reduction is illustrated in Figure 4.2. While the phantom load size is relatively small the functionality observed is an important development and achievement for home energy automation as well as from a regional, provincial or national energy management strategy. Here we see the default scenario constantly consuming 19.6 watts.

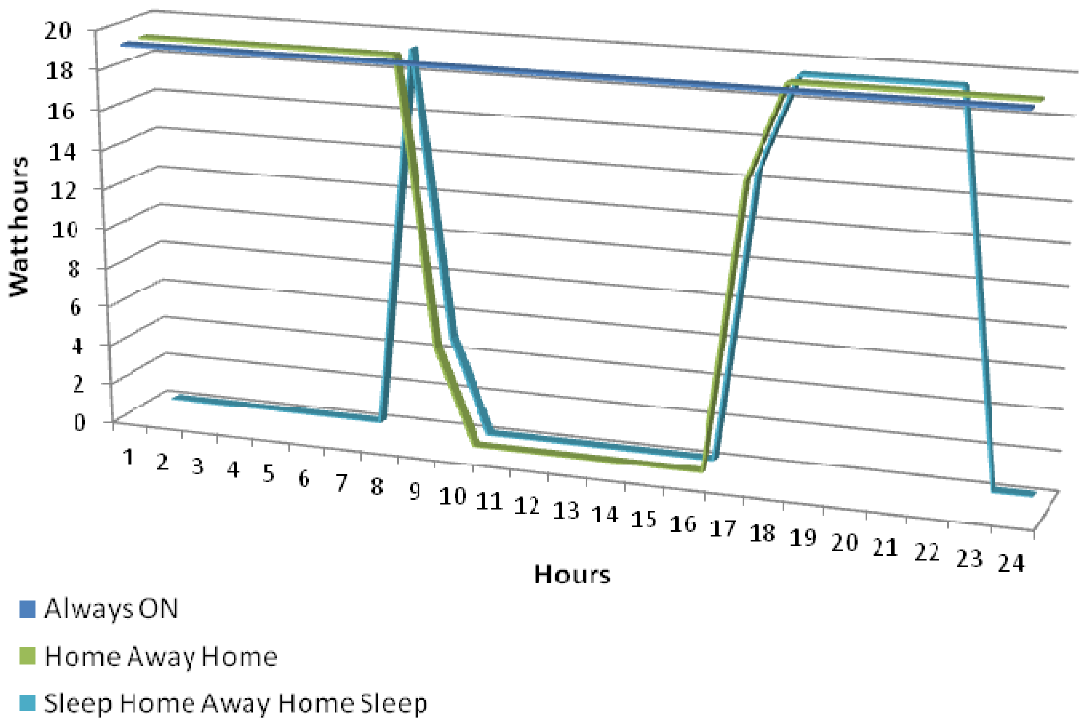

Figure 4.2: Phantom Load Reduction from a stereo system

The second test scenario shows how the phantom load is eliminated during the time that the homeowner is out of the home from 8:45 am to 4:15 pm. In the third test scenario the phantom load is eliminated for the same time period that the homeowner is away, but also from 10 pm through to 7 am when the homeowner wakes, and activates the home switch. The total run time that the receptacle is enabled and the appliance is experiencing standby losses falls from 24 hours in the first scenario, to 16.5 hours in the second scenario, and is reduced to a total of 7.5 hours in the third test scenario.

While the actual costs savings of individual appliance phantom load reductions are quite small, the aggregate of phantom loads in a home (1.17 kWh per day) reported by Fung et al. (2003) is much more significant. The ability to turn off these collective appliances particularly during times of peak when electricity is most expensive is an important component of efficient and optimized home energy management. The total daily aggregate of phantom loads in this test, is1.2 kilowatt hours. an annual cost savings of up to 60% was obtained from applying the control strategies utilized in this study to phantom loads (Figure 4.3).

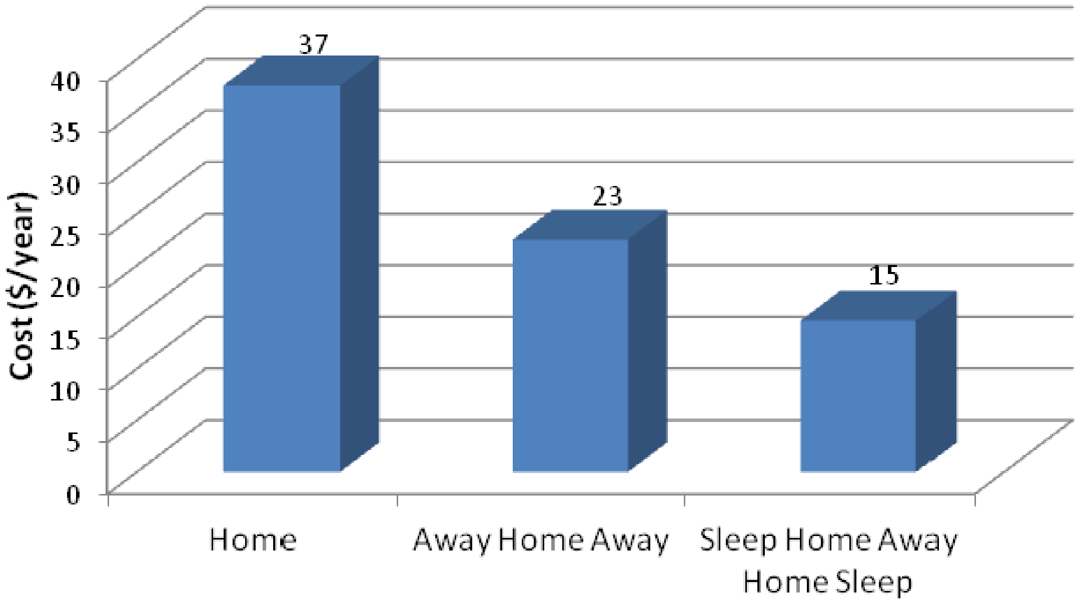

Figure 4.3: Annual cost of phantom loads under three scenarios

4.4 Lighting

Lighting controls present a large potential opportunity for reduction and cost savings through devices like the dx2 management system. In synthetically derived profiles published by Armstrong et al. (2009), lighting accounts for between 20 and 30 percent of total electrical loads.

Tests done in this study assumed that both the first and second scenarios would use the *Home and Away* settings for lighting. This was done based on the assumption that it may be rare for a homeowner to leave all lights on when leaving the home. (Whether this is a reasonable assumption, and how long lights are left on in a typical family is a subject for further study.) The third test scenario utilizes the *Home*, *Away* and *Sleep* mode functions. For comparison, models associated with an *on all the time*, *Home and Away*, and *Home, Away, Sleep* modes, as well as very significant related costs are also presented in Figures 4.4 and 4.5.

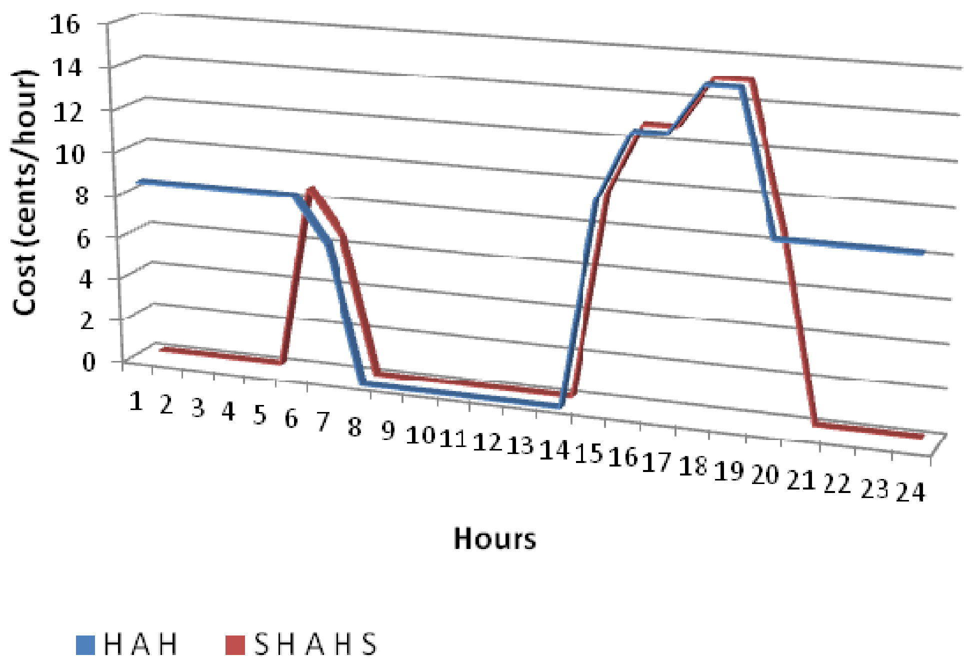

Figure 4.4: Hourly costs associated with the two test scenarios. Scenario 1 was identical to scenario 2, and is therefore not shown.

By turning all hard wired lighting off while the homeowner is away from home (8:45 am to 4:15 pm), dx2 has the capacity to reduce electrical consumption and associated costs. This includes the ability to shut off these circuits for mid peak and for just over 2 hours during morning peak, from 8:45 am to 11 am. Enabling the *sleep* mode further reduces the lighting load from 16.5 hours of operation in the *Home and Away* scenario, to a total of 7.5 hours in the third scenario (Figure 4.4).

This opportunity is illustrated in the example of the modeled hard-wire lighting scenarios in the test. In these scenarios, not only is total consumption reduced, but consumption is also reduced specifically at peak times when electricity is most expensive. In the *Home* scenario, hard wired lighting is not controlled and is modeled as being on all the time. In the *Home-Away-Home* scenario, lighting is automatically shut off when the *away* switch is activated, and the home is unoccupied. In the final *Sleep-Home-Away-Home-Sleep* scenario, lighting is also deactivated by the Night mode button when the occupants are asleep. While light switching in each of these scenarios can be controlled entirely by the occupant simply by switching off all lights before leaving the home and before going to bed, the convenience of a central location/switch can be appealing for someone not willing or not in the habit of performing these functions, or someone who likes to have this ability as a fallback option. In the case of dx2, this built-in capacity is also available remotely over the internet with the use of a remote computer. In this study remote access was carried out with the use of Team Viewer software. Future versions of the dx2 system will include the ability to control settings from a smart phone. The resulting hourly operation and total annual consumption costs of these different models are shown in Figures 4.5 and 4.6.

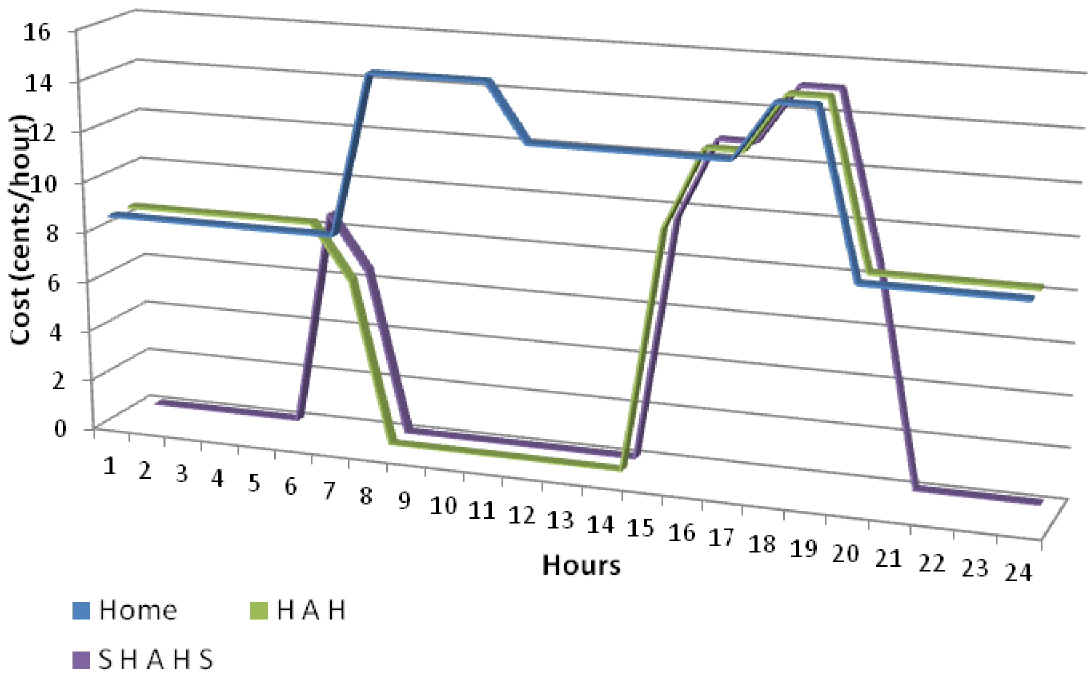

Figure 4.5: Modeled Hard wire lighting hourly costs for three scenarios

Figure 4.5 shows the effects of time of use pricing in the *Always Home* scenario. In this situation we see how the cost of electricity at peak and mid peak increases the baseline energy use cost of hard wired lighting. This is of particular importance when viewed in light of the fact that this is also likely to be the time when the house is vacant and lighting is not required. This has the potential to eliminate one of the most inefficient uses of electricity for the homeowner, a given region, as well as on a national scale.

When looking at the effects of these costs over the course of a year it becomes evident that significant cost savings are achieved with the application of the *Home, Away* and *Sleep* modes from the dx2 system. While it is unlikely that homeowners would leave lights on when they leave the house or go to bed at night, the lights on all the time scenario offers important insight as a comparative reference point to the application of system modes and their associated cost savings with regards to hard wired lighting.

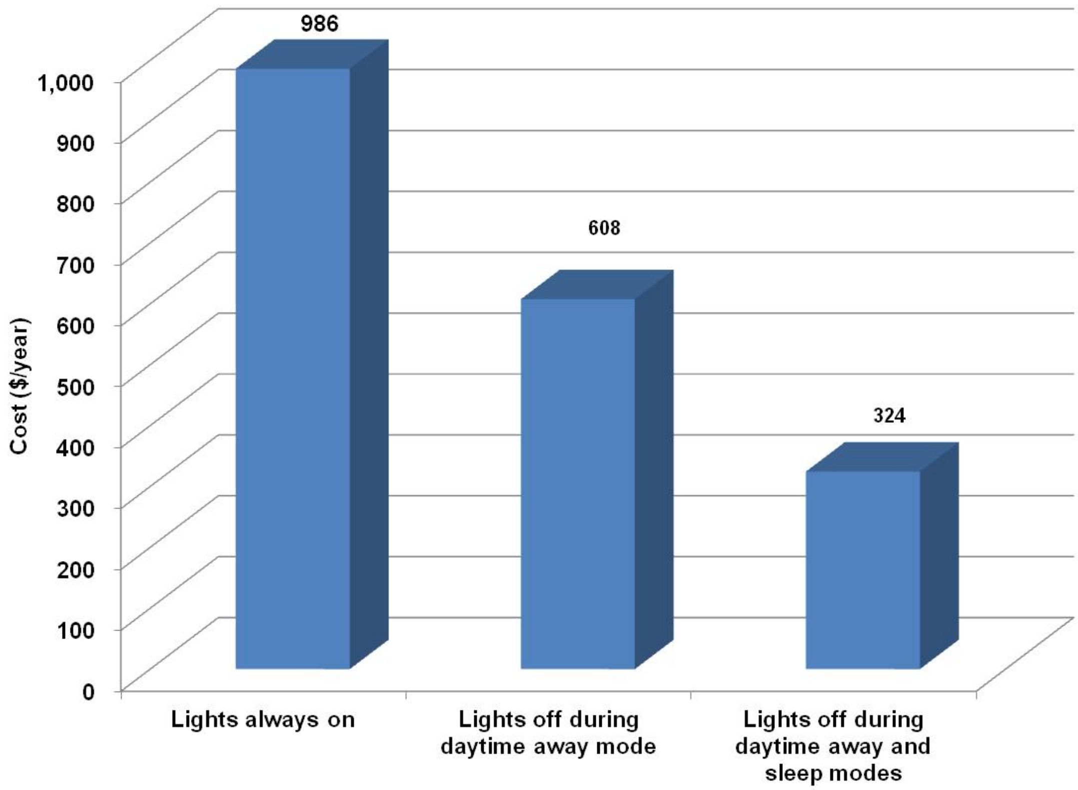

Figure 4.6: Annual hard-wired lighting costs under three scenarios

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results from this study show strong potential cost and energy savings related to three major applications of the dx2 monitoring and control system. The first area is in the elimination or reduction of phantom loads. This has an important effect for the individual home owner in terms of cost savings, as well as significant potential for the utility to help reduce regional or provincial base loads particularly at peak. The annual aggregate cost of phantom loads were reduced by up to 60 percent over the three test scenarios. Costs fell from an annual value of $37.44 without control features, to an annual cost of $14.67 utilizing the *home*, *away* and *sleep* mode system controls.

Another similar yet even greater potential for cost savings than the elimination of phantom loads, is the reduction or elimination of base loads in the home. This is of particular importance during peak times for the homeowner, when the cost of electricity is at a premium, as well as for the utility, as this area is likely to represent the most significant opportunity to reduce peak demand. Reducing the operation of select base loads in the form of plug and exterior lighting (135 watts) showed annual savings of approximately $63 between the highest and lowest energy use scenarios tested. For the utility, the consumption reductions from scenario 1 to 2 and 1 to 3 are 31% and 69%, respectively. If this model of energy savings is applied on a scale of 500 homes over the course of a year, the net reduction is 406 MWh. If we compare this to the annual, medium use energy profile from Armstrong et al. (2009) of 8156 kWh, we find net energy savings to power an additional 50 homes.

The significant potential that this energy management and control system can provide in terms of energy use reductions and cost savings, suggests that a broad adoption into homes across a region can have significant benefits to both the homeowner and electrical utility. A further advantage of utilizing this technology comes in the form of the potential management of a demand response event from a local utility. This refers to the opportunity to remotely control electrical consumption when a utility is experiencing an exceptionally high peak period. Through existing peak saver programs offered by utilities, peak demand can be reduced by remotely controlling programmable thermostats and reducing air conditioning loads in participating households. A residential energy monitoring and control system such as dx2, can act like a programmable thermostat for multiple electrical loads by programming system preferences specific to a peak saver event. This would have the effect of significantly reducing peak demand and assisting the utility in fulfilling its role of efficiently supplying electricity to all portions of the grid.

In this study we have shown that the dx2 system can successfully control the operation of base loads. It is important to note that the feasibility for base loads to be shut off or controlled needs to be investigated through the course of future studies. The feasibility by which base loads can be shut on and off, cycled, or partially run, is of particular importance to the overall feasibility of the dx2 system and could represent the opportunity to go above and beyond the energy and cost savings demonstrated in this study

One strategy for energy use reductions and cost savings for homeowners, including load control, peak shaving and the elimination of phantom loads, is to work out optimal scenarios with the use of a simple spreadsheet tool, allowing users to simply control electrical loads through the use of individual timers and power bars. With some thought and consideration, this type of approach can largely perform the same basic control measures as the dx2 system evaluated in this study, albeit much less conveniently. Major advantages of the dx2 system over this timer and power bar strategy, include the ability to modify settings and controls remotely, monitor and observe the energy use and patterns of consumption for individual and household energy consumption over variable time periods, and to control individual appliances and hard-wired circuits from one central location. These and other benefits associated with electrical safety and home security offer significant value in the convenience of behavioral modification that can lead to systematic and lasting change in the optimization of household energy use patterns.

Further developments of the dx2 system could include the potential to visualize graphs with cost savings across multiple scenarios; allowing the homeowner to pick and choose his home energy settings with a predictive function allowing the individual to balance potential savings and lifestyle choices.

This study illustrates how cost savings and energy use reductions can be obtained through both automated controls and user based behavioral change. The dx2 individual load control settings for the *home*, *away* and *sleep* modes have been shown to be useful when activated by the homeowner. When comparing this system to the manual power bar and individual timer scenario, the system provides clear value both in minimizing the time resource invested to obtain the desired energy savings, and in providing feedback on home energy and water use that can further motivate changes in behavior.

Other dx2 settings such as the energy saver modes (*e.g.* use device low peak only, turn device off during peak), and customized timers, once successfully implemented can offer an added degree of automation that could potentially eliminate the need for the homeowner to activate the *home*, *away* and *sleep* modes. This potential range of control options can offer significant flexibility to the homeowner in finding a strategy that best optimizes their schedule and lifestyle. How the homeowner chooses to use the system, and how the information provided through the system influences the homeowner's behavior, will ultimately determine what benefits the system provides, not only to the homeowner, but also to the utility and the environment.

5.1 Recommendations

5.1.1 System Functionality

This prototype version of dx2 offers important control features to the homeowner. There are extensive options for the types of controls that the homeowner may wish to incorporate as part of their home energy management and optimization strategies.

The primary means of control utilized throughout this study is the system mode, which designates preferences per appliance based on whether the homeowner has activated the *Home*, *Away* or *Sleep* mode settings. An energy saver setting can enable receptacles all the time, during low peak only, or not at all during peak. Customized timers provide additional functionality in conjunction with the system mode and energy saver settings. There is also an option to set appliances from sunrise to sunset and from sunset to sunrise.

In the version tested, the logic of the control systems and system functionality had not been optimized. Various system functionality issues were identified during the study and specific recommendations were provided to the manufacturer for consideration in future versions of the system. It is our understanding, at the time of writing, that many of these issues have already been addressed in a more recent version of the system.

5.1.2 Further Study Needs

This study has highlighted a number of areas that are in need of further study. These include the following:

- While there are data on average household energy consumption, these aggregated datasets do not include detailed information on plug loads, hard wired lighting or specific appliance uses, and are not related specifically to various building occupancy patterns. These data are critical to providing accurate estimates of the potential cost and energy savings associated with energy monitoring and control systems.
- Further data and information on the potential consequences of operating appliances such as freezers, refrigerators, HEPA air filters and HRV systems on time schedules is needed to determine whether these relatively high energy uses could be controlled by centralized energy control systems.
- More research is needed on the potential of these systems to participate in emerging energy savings opportunities involving fuel switching, electrical vehicle charging, optimization of photovoltaics for peak shaving and other applications that may have more significant load reduction and/or peak shifting benefits than were documented in this study.
- A study should be conducted comparing energy use profiles of several households before and after installation of the system in order to better understand how typical households may program and derive energy savings benefits from the system.

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APPENDIX A

dx2 smartwave Slides

smartwave™

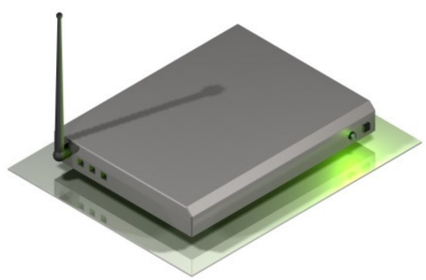
dx2 technologies

March 2012

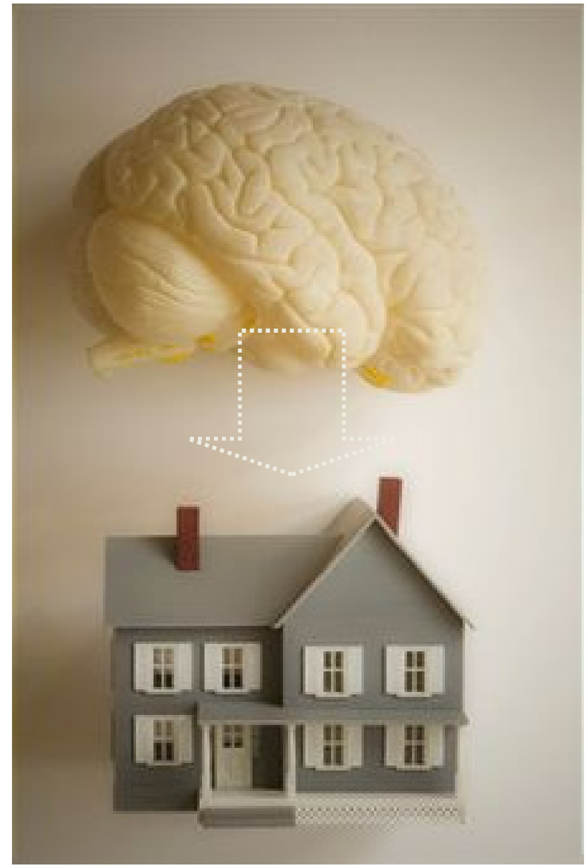
david adey, don martone

Building Intelligence … for your smart home today™

- Automation
- Energy Savings
- Safety / Security
- Smart Grid Connectivity



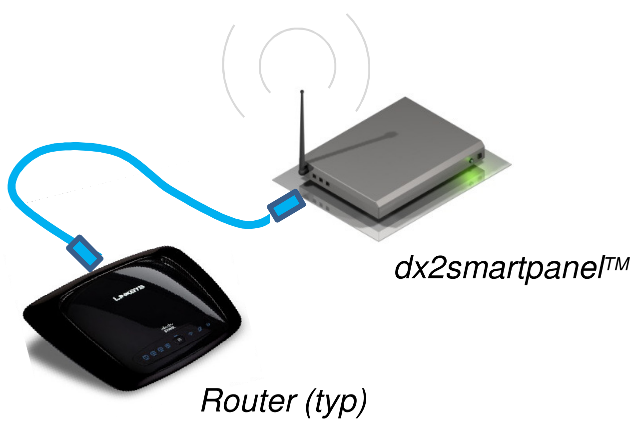
dx2smartpanel™



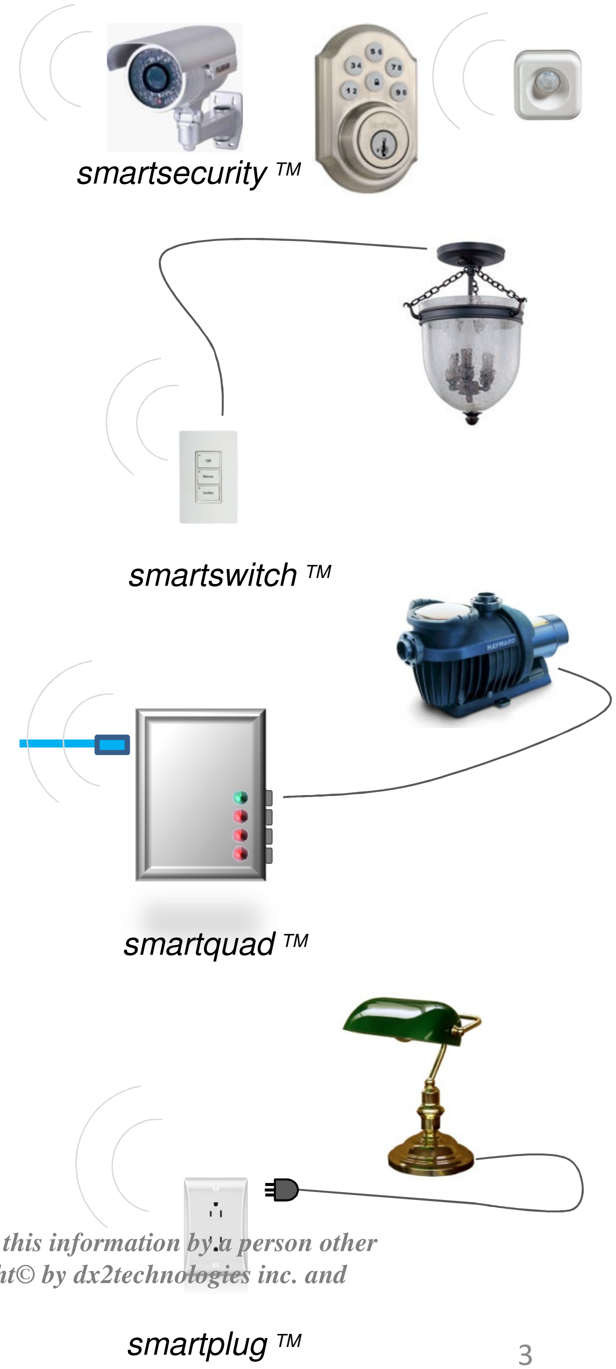
System Elements

Elegance in its simplicity …

- plug + play
- flexibility
- expandability



… install the hardware and system will auto configure…



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Today: Mostly Cloudy Temp: 15 C

Sunrise: 7:12 am Sunset: 7:34 pm

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