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The Effects of Thermostat Set-back and Set-up on Seasonal Energy Consumption, Surface Temperatures and Recovery Times at the CCHT Twin House Facility

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ABSTRACT

During the winter heating season of 2002-2003 and the summer cooling season of 2003, the Canadian Centre for Housing Technology (CCHT) ran a series of trials to determine actual energy savings from thermostat setting in one of its R-2000 test houses. The unique nature of the CCHT Twin House Facility allowed not only the examination of energy savings, but also whole house performance. During the thermostat experiments, important factors that affect occupant comfort were explored, including: air temperature recovery time from set-back and set-up, house surface temperatures during winter set-back, solar effects, and summer house humidity: giving a broad picture of the effects of thermostat set-back/set-up in a typical R-2000 home.

INTRODUCTION

The Canadian Centre for Housing Technology (CCHT) is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. CCHT is home to a unique facility of identical two-storey R-2000 houses (R-2000 is an official trademark of Natural Resources Canada). These twin houses feature a simulated occupancy program, and are fully instrumented with over 300 sensors. Since its launch in 1998, the facility has been the site of many energy-related side-by-side evaluations of heating and cooling technologies. Evaluated technologies include: natural gas-fired combo systems (Swinton et al. 2000), the electronically commutated motor (Gusdorf et al. 2003), indoor and outdoor blinds (Galasiu et al. 2005), and modified air circulation (Gusdorf et al. 2005).

CCHT researchers identified the need to evaluate the effect of thermostat setting on energy savings in a house built to R-2000 standards using a passive solar strategy. Since the CCHT twin-houses are highly energy efficient with a recently measured airtightness of 1.5 air changes per hour @ 50 Pa (1.0 lb/ft^2), slow decreases in indoor temperature during a set-back were anticipated, and so the benefits of thermostat set-back were expected to be minimal. By the same token, summer heat gains through the 16.2 m^2 (174 ft^2) of south facing low-e coated argon-filled windows were expected to be substantial, so large benefits from summer set-up were expected. The instrumented facility allowed not only for the evaluation of energy savings during the study, but also permitted researchers to draw an overall picture of the house's performance. Solar effects, temperature recovery times and winter surface temperatures were among the evaluated factors. This paper presents the results of this study.

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BACKGROUND

The concept of adjusting thermostat setting in order to achieve energy savings is by no means new. Pilati (1976) performed detailed simulations of a typical house in a variety of U.S. climates. Pilati estimated that with the proper incentives, homeowners would make changes in home thermostat settings that could reduce U.S. energy consumption by approximately 4.4%. Nelson and MacArthur (1978) modeled daytime and nighttime thermostat set-back strategies, revealing furnace gas savings ranging from 15 to 25%. The use of thermostat set-back in energy efficient houses has also been explored. Poehlman et al. (1988) concluded that set-back thermostats are of questionable value and may even be counterproductive in a home built to R-2000 standards. Most recent temperature control studies including Thomas (2005), Maheshwari (2000), Raja (2001) and Armstrong et al. (1992a, 1992b), have centered on energy savings in commercial buildings, rather than the residential sector.

As energy costs increase, the lifestyle changes decribed by Pilati and other researchers in the 1970's are quickly becoming a reality. Regularly lowering the temperature on a thermostat overnight or while away from home to conserve energy is a common habit among Canadians. In 1994, over 70% of Canadians claimed to practice this habit, while only a small portion, 16%, claimed to own a programmable thermostat (Statistics Canada 1994). Currently, there is an increasing trend towards the use of programmable thermostats in North America: thermostat vendors and manufacturers are reporting increases in sales, aided by rising fuel costs and high heating bills (Blum 2005). With programmable thermostats comes the ability to program different strategies for additional savings in summer and winter. This initiative is being directly fueled by the Energy Star program. In order to qualify for the Energy Star rating, a thermostat must be programmable and come preset with a heating set-back and cooling set-up program (Energy Star 2005). Required pre-programming includes both daytime and nighttime temperature adjustment. An acceptable program is listed in Table 1.

With both programmable thermostats and energy efficient houses becoming more prevalent, side-by-side testing is needed to determine whether a programmable thermostat offers any substantial savings to a homeowner with an efficient house, and whether these savings come at a cost of discomfort to the homeowner or risk of damage to the home through repeated envelope surface condensation.

Table 1 Energy Star Acceptable Setpoint Times and Temperature Settings (Energy Star 2005)

Setting	Time	Setpoint Temperature	
		Heat	Cool
Wake	6 a.m.	70°F (21°C)	78°F (26°C)
Day	8 a.m.	62°F (17°C)	85°F (29°C)
Evening	6 p.m.	70°F (21°C)	78°F (26°C)
Sleep	10 p.m.	62°F (17°C)	82°F (28°C)

OBJECTIVES

The objectives of the project were twofold:

1. To directly measure energy savings from different thermostat strategies in an R-2000 home.
2. To determine the effect of thermostat setting on whole house performance, including recovery times that could adversely effect occupant comfort, as well as winter surface temperatures that could lead to potential condensation problems.

EXPERIMENTAL SETUP

Description of CCHT Twin Houses

The CCHT Twin Houses are located on the National Research Council Montreal Road Campus in Ottawa, Ontario, Canada. Features of the houses are listed in Table 2. In addition to these features, the houses include a simulated occupancy system that simulates the daily water draws and electrical loads of a family of four. The internal heat gains from the occupants are also simulated, through the use of 60 W (adult) and 40 W (children) light bulbs.

Table 2 CCHT Research House Specifications

Feature	**Details**
Construction Standard	R-2000
Liveable Area	210 m^2 (2260 ft^2), 2 storeys
Insulation	Attic: RSI 8.6 (R-49), Walls: RSI 3.5 (R-20), Rim joists: RSI 3.5 (R-20)
Basement	Poured concrete, full basement Floor: Concrete slab, no insulation Walls: RSI 3.5 (R-20) in a framed wall. No vapour barrier.
Garage	Two-car, recessed into the floor plan; isolated control room in the garage
Exposed floor over the garage	RSI 4.4 (R-25) with heated/cooled plenum air space between insulation and sub-floor.
Windows	Area: 35.0 m^2 (377 ft^2) total, 16.2 m^2 (174 ft^2) South Facing Double glazed, high solar heat gain coating on surface 3. Insulated spacer, argon filled, with argon concentration measured to 95%.
Air Barrier System	Exterior, taped fiberboard sheathing with laminated weather resistant barrier. Taped penetrations, including windows.
Airtightness	1.5 air changes per hour @ 50 Pa (1.0 lb/ft^2)
Furnishing	Unfurnished

Approach

The thermostat setting study took place in the winter of 2002/03 and the summer of 2003. A side-by-side testing approach was used, as outlined by Swinton et al. (2001). Initially the houses were “benchmarked” in identical configuration with matching thermostat settings, in order to identify small differences in house performance. Following an initial period of benchmarking, different thermostat strategies were deployed in one of the houses, referred to as the “Test House”. The second house, referred to as the “Reference House”, remained at a control setting of 22°C (72°F) without winter set-back or summer set-up. Benchmarking also occurred in between strategies and following the experiment to ensure that house performance remained unchanged.

Three different set-back temperature strategies were deployed in the Test House during winter testing. These strategies are outlined in Table 3. During summer testing, two different temperature strategies were tested. The first strategy employed a 3°C (5°F) daytime set-up, while the second was simply a higher temperature setting: 24°C (75°F) 24 hours per day. The range of outdoor temperatures and the number of test days for each benchmarking period and experiment strategy are listed in the last two columns of Table 3.

Table 3 Test Days and Outdoor Temperature

Strategy	Winter: Set-Back Temperature from 22°C (72°F) Summer: Set-up Temperature from 22°C (72°F)	Time Period	Number of Test Days *	Range of Outdoor Temperature °C (°F)
W0) 22°C (72°F) Winter Benchmark	-----	-----	28	-22 to 15 (-8 to 59)
W1) 18°C (64°F) Nighttime Set-back	18°C (64°F)	23:00 - 6:00	12	-27 to 4 (-17 to 39)
W2) 18°C (64°F) Day and Night Set-back	18°C (64°F)	23:00 - 6:00 9:00 - 16:00	15	-23 to 1 (-9 to 34)
W3) 16°C (61°F) Day and Night Set-back	16°C (61°F)	23:00 - 6:00 9:00 - 16:00	7	-27 to 3 (-17 to 37)
S0) 22°C (72°F) Summer Benchmark	-----	-----	27	8 to 35 (46 to 95)

S1) 25°C (77°F) Daytime Set-up	25°C (77°F)	9:00 - 16:00	20	5 to 31 (41 to 88)
S2) 24°C (75°F) Temperature Setting	24°C (75°F)	0:00 - 24:00	14	9 to 29 (48 to 84)

*Note: test days were not necessarily consecutive. In the case of Benchmarking, groups of test days were spread throughout the season.

Mechanical Equipment

A single centrally located programmable thermostat, featuring conventional recovery (system activation at the time of temperature setting change), controlled both the space heating and cooling systems. Features of the thermostat included: a 2°C (4°F) nominal deadband, and a cycle rate of 3 cycles/hr when at the 50% load condition.

Both houses were equipped with a gas furnace @ 80% efficiency (measured) with a standard permanent split capacitor (PSC) motor. The choice of the mid-efficiency furnace over the high-efficiency furnace was made for a separate experiment during the same season: using the same furnace allowed both projects to share benchmark data. The furnace motor operated in low-speed continuous circulation when not providing high-speed distribution for space heating or cooling. The rated output of the furnace was 71.2 MJ/h (67,500 Btu/h). A 12 SEER (nominal) air conditioning unit with 2 ton capacity provided cooling. A heat recovery ventilator (HRV) @ 84% efficiency (nominal) operated at low speed (1.8 m^3/min [65 cfm]) continually throughout all trials. Hot water heating was provided by a conventional, induced draft water heater @ 67% efficiency (measured).

Air is distributed throughout the house via sheet metal ducting. Supply registers and air returns are located on all three floors: nine supply registers, and two return grilles on the first floor; 11 supply registers and five return grilles on the second floor; and three supply registers and a single return grille in the basement. Air is supplied at approximately 620 L/s (1310 cfm) in heating mode, 680 L/s (1440 cfm) in air conditioning mode, and 450 L/s (950 cfm) in continuous circulation, as per the furnace motor's standard operating speeds.

Data collection

Consumption data consisting of: air conditioner compressor electrical consumption, furnace fan electrical consumption and furnace gas consumption were collected on a 5-minute basis by means of pulse-meters at a resolution of 0.0006 kWh/pulse (2.0 Btu/pulse) and 1.4 L/pulse (0.05 ft^3/pulse). The total daily consumption values were calculated based on these data.

Temperature data were collected throughout the house, including: thermostat temperature, room air temperature, window surface temperature, and drywall surface temperature. Window surface temperatures were collected on the interior surface of three separate windows at the centre of the fixed pane, at the bottom edge of the fixed pane, at the bottom edge of the openable window pane, and on the frame at the base of both the openable and fixed window. Drywall surface temperatures were collected at six different locations in the house. All drywall surface thermocouples were positioned at mid-wall height over an insulated stud space. With the exception of thermostat temperature, all temperature data were collected every five minutes, averaged and recorded hourly. Thermostat temperature was recorded on a 5-minute basis.

A precision spectral pyranometer was mounted vertically on the south face of the Reference House measured total incident solar radiation during summer testing. A threshold value of 8500 kJ/m^2/day (748 Btu/ft^2/day) was chosen to differentiate between days with "high" solar gains and days with "low" solar gains.

Analysis

Furnace and air conditioner consumption were compiled on a daily basis from 5-minute data. By plotting the daily consumption of the Test House vs the Reference House, trends were developed for each thermostat setting across a range of environmental conditions (see Figure 2 for an example). Using the Reference House consumption as a reference, the benchmark line correlation was used to calculate the amount of energy consumed by the Test House without the thermostat strategy for any given day of the thermostat experiments. Daily savings were determined by comparing the Test House consumption with thermostat strategy to the calculated Test House consumption under benchmark conditions (see Appedix A for tables of daily savings). The advantage of using the Reference House as a reference, instead of depending on correlations with outdoor temperature, is that both houses are exposed to identical outdoor conditions. This allows the effects of the thermostat setting to be isolated from wind, solar and temperature effects. The total seasonal savings from each strategy in the Test House were calculated using the consumption trends, based on a binning method and a complete year of consumption data from the CCHT Reference House. The detailed seasonal energy savings calculation method is outlined in *Annual Energy Consumption Analysis of the CCHT Research Houses* (Manning, in prep.).

The houses were not humidified during winter testing, so condensation on cold surfaces was not directly observed. During each winter thermostat strategy, the minimum measured drywall and window surface temperatures were determined. Dewpoint temperature equations (ASHRAE 2005) were then used to determine the relative humidity of air at 22° C (72°F), which is required to cause dew-point conditions to be present at the wall or window surface. This is only a rudimentary indication of the potential for condensation. Modelling is required to account for material characteristics before condensation problems can be suitably predicted.

Recovery time was defined for the purpose of these experiments as the time required for the air temperature beside the thermostat to return to the original temperature setting following a set-up or set-back period. To identify this “original temperature”, or threshold for recovery, the 22°C (72°F) benchmark condition was examined. Benchmark temperature data were used to determine the relationship between the average daily main floor temperature of the Reference House and that of the Test House. On any given set-up or set-back experiment day, this main floor temperature correlation and the Reference House main floor temperature were used to predict the average main floor temperature of the Test House if the house were maintained at a constant 22°C (72°F). This “expected average” was then set as the threshold temperature for recovery.

WINTER RESULTS

Winter Energy savings

Tables 4 and 5 list the calculated seasonal savings from the use of the three different set-back strategies in the CCHT Test House. Detailed daily gas consumption savings data is also presented in Appendix A, Table A-1. These seasonal savings are based on a winter season with 4671 heating Celsius degree days <18°C (8408 Fahrenheit degree days <64°F). Additionally, the calculated savings for the test day with the highest heating load during the test season (January 22nd 2003, high -19°C [-2°F], low -27°C [-17°F]) is listed in the final column of the tables, under the heading “coldest day savings”.

Table 4 Calculated Furnace Gas Consumption Savings (based on experiment trends)

Strategy	Total Winter Furnace Gas Consumption MJ (Btu)	Seasonal Savings (%)	Coldest Day Savings (%)
W0) 22°C (72°F) Winter Benchmark	66 131 (6.2680×10^7)	----	----
W1) 18°C (64°F) Nighttime Set-back	61 854 (5.8626×10^7)	6.5	11
W2) 18°C (64°F) Day and Night Set-back	59 231 (5.6140×10^7)	10	17
W3) 16°C (61°F) Day and Night Set-back	57 241 (5.4254×10^7)	13	21

Table 5 Calculated Furnace Fan Electrical Consumption Savings (based on experiment trends)

Strategy	Total Winter Furnace Electrical Consumption (kWh)	Seasonal Savings (%)	Coldest Day Savings (%)
W0) 22°C (72°F) Winter Benchmark	2314	----	----
W1) 18°C (64°F) Nighttime Set-back	2295	0.8	4.1

W2) 18°C (64°F) Day and Night Set-back	2270	1.9	6.7
W3) 16°C (61°F) Day and Night Set-back	2261	2.3	8.4

Energy savings from the three different winter set-back strategies were significant. Despite the energy efficient construction of the house, air temperatures reached or dropped below the set-back temperatures on the majority of test days. In general, both furnace gas and electrical savings were highest on the coldest cloudiest days of testing – days with the highest heating loads. Savings also increased with longer set-back periods and lower thermostat temperatures, the 16°C (61°F) day and night set-back offering the highest savings of all three winter strategies. Gas savings trends are featured in Figure 1. The three set-back trends intercept the benchmark line between a Reference House consumption of 187 and 208 MJ/day (1.77×10^5 and 1.97×10^5 Btu/day). On days where the Reference House consumes less than 187 MJ/day (1.77×10^5 Btu/day), savings from set-back would be minimal. This threshold consumption corresponds to an average outdoor temperature of approximately 4°C (39°F).

Furnace electrical savings are lower than gas consumption savings, due to the fact that the furnace motor ran in continuous operation throughout all trials, providing low speed circulation when not in heating mode.

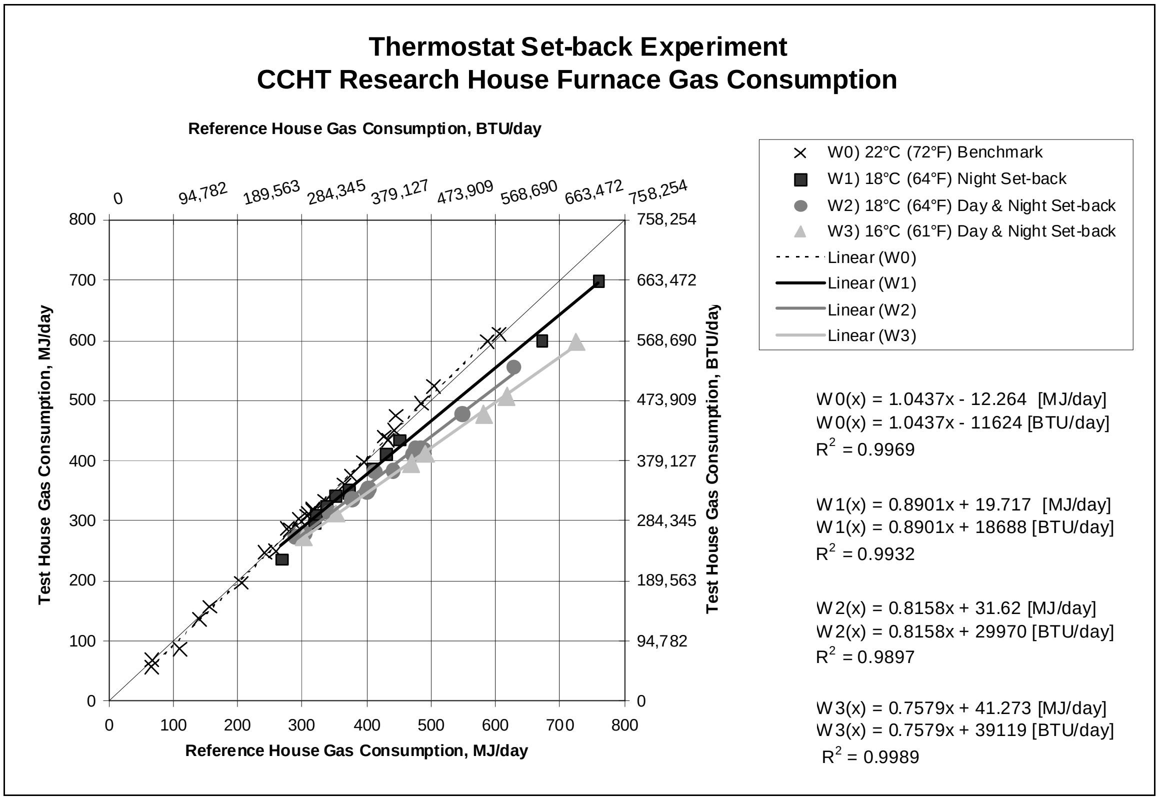

Figure 1 Winter Gas Consumption Trends

Winter Recovery Times

Winter recovery times were directly related to the minimum temperature reached by the air beside the thermostat during the set-back period – the lower the temperature reached, the longer the recovery time. This relationship is plotted in Figure 2. The longest recovery time recorded was 2.25 hours, occurring after a nighttime 16°C (61°F) set-back during which the air temperature beside the thermostat had dropped to 14°C (57°F). Temperatures during the setback often dipped below the thermostat setting. This phenomenon is believed to be a function of the accuracy of the thermostat control and the size of the deadband. In benchmarking configuration, when the thermostat is set to 22°C (72°F), the house is maintained at 21°C (70°F) with a 2°C (4°F) deadband (between 20°C [68°F] and 22°C [72°F]). A 16°C (61°F) setting would be expected to produce a deadband between 14°C (57°F) and 16°C (61°F). This is consistent with the minimum temperatures observed.

On certain test days when the main floor temperature dropped to below 16.5°C (61.7°F), the furnace ran more than once to reach the desired set point. This is attributable to the thermostat shutting off the furnace before reaching the set point temperature as a result of its programmed cycle rate. As the temperature at the thermostat approaches the 50% load condition, within 2°C (3.6°F) of the setpoint, the thermostat beings to cycle automatically 3 times/hr, even if it has not attained the desired recovery temperature. As a result, the recovery time was increased. Data points where more than one furnace run was required to recover the house temperature are circled in Figure 3. These points were included in the correlation. The two points with a low minimum main floor temperature that only took a single furnace cycle to reach the recovery temperature just barely exceeded it, by ~0.1°C (0.2°F), before the furnace began its cycling routine.

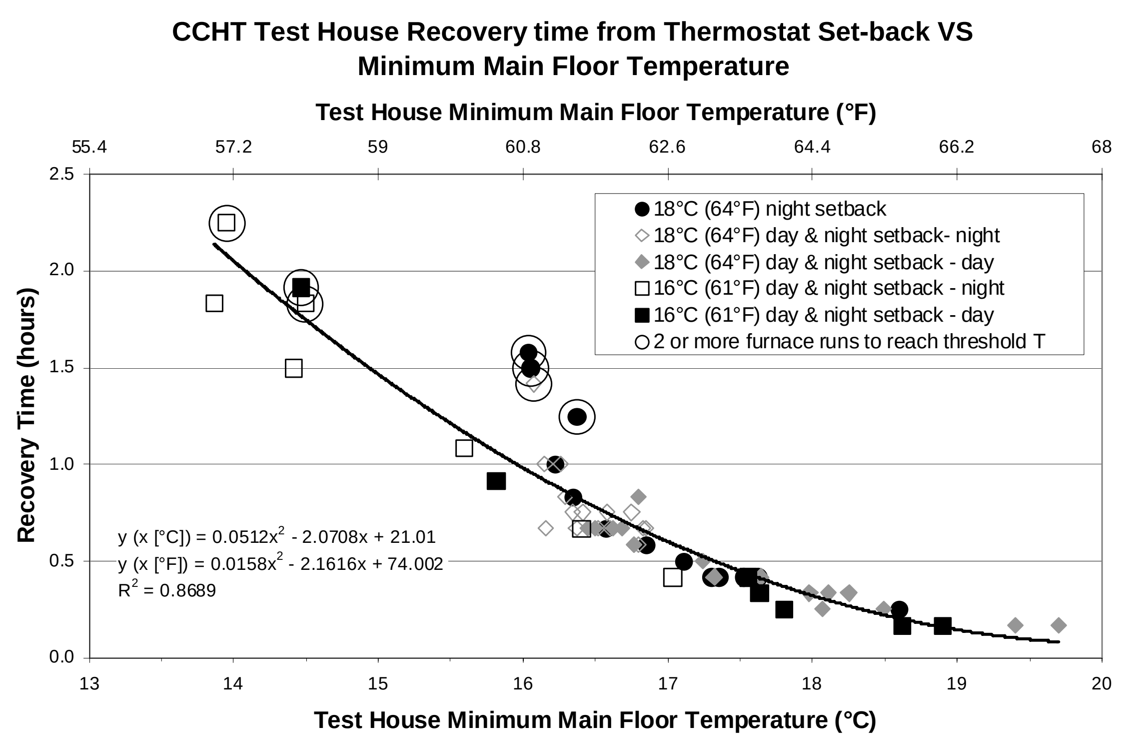

Figure 2 Winter Recovery Time VS Minimum Main Floor Temperature

Surface Temperatures

Window surface temperatures in the Reference House dropped to as low as –0.9°C (30°F) on the coldest nights. The coldest window surface temperatures were recorded on the window frame of the operable window. At this low temperature, dewpoint conditions would be met by air with a relative humidity in excess of 22% @ 22°C (72°F). By coincidence, the lowest outdoor temperature reached during both the 16°C (61°F) and 18°C (64°F) set-back trials was –27°C (-17°F). During the set-back strategies, window frame temperatures dropped to as low as –4.9°C (23°F) (at an 18°C [64°F] set-back) and –7.8°C (18°F) (at a 16°C [61°F] set-back) in the Test House. Dewpoint conditions would be met by air exceeding 16% or 13% @ 22°C (72°F). Predictably, drywall surface temperatures were warmer than window surface temperatures. Measured drywall surface temperatures remained above 17.8°C (64.0°F) in the Reference House (with a setpoint of 22°C [72°F]) throughout the experiment. The depoint conditions would be met by 22°C (72°F) air with a relative humidity above 78%. In the Test House, measured drywall surface temperatures dropped as low as 14.9°C (58.8°F) during the 18°C (64°F) set-back strategies, and 12.7°C (54.9°F) during the 16°C (61°F) set-back strategy. Dewpoint conditions would be met by 22°C (72°F) air with relative humidities above 64% and 55% respectively. Even cooler temperatures would be expected on surfaces in the home that are not directly over an insulated stud space.

SUMMER RESULTS

Summer Energy savings

The two different summer thermostat strategies yielded two very distinct results in terms of energy savings. Table 6 lists the calculated savings from summer thermostat strategies. Detailed daily electrical consumption savings data is also presented in Appendix A, Table A-2. Seasonal savings are based on a cooling season with 362 Celcius cooling degree days >18°C (652 Fahrenheit cooling degree days >64°F). Hottest day savings were calculated for June 26th 2003 (high 35°C [95°F], low 23°C [73°F]). The first summer strategy, a temperature set-up from 22°C (72°F) to 24°C (75°F) during the day, yielded a seasonal savings of approximately 11%. The highest savings from this strategy were seen on the hottest/sunniest days – with the highest cooling load. Dividing the set-up data into days with low and high solar gains revealed that the set-up strategy was greatly affected by solar radiation. On days with low solar gains, the savings from set-up were minimal. If all days in the summer had low solar gains, a savings of only 2.8% would be expected using this strategy.

By contrast, energy savings from the higher temperature setting, 25°C (77°F) for 24 hours per day, were largely unaffected by solar gains. The higher setting trend line, shown in Figure 4, remained almost parallel to the benchmark trend, achieving 5 kWh of savings per day across a full range of outdoor conditions. This trend is a direct result of the 2°C (3.6°F) offset from the benchmark condition. A savings of 23% in seasonal air conditioning and furnace electrical consumption is predicted for this strategy. This is more than double the predicted savings from the thermostat set-up.

Table 6 Calculated Furnace and Air Conditioner Electrical Consumption Savings
(based on experiment trends)

Strategy	Total Summer Furnace and Air Conditioning Electrical Consumption (kWh)	Seasonal Savings (%)	Warmest Day Savings (%)
S0) 22°C (72°F) Summer Benchmark	3099	----	----
S1) 25°C (77°F) Daytime Set-up	2767	11	14
• High solar gains	2690	13	
• Low solar gains	3010	2.9	
S2) 24°C (75°F) Temperature Setting	2376	23	17

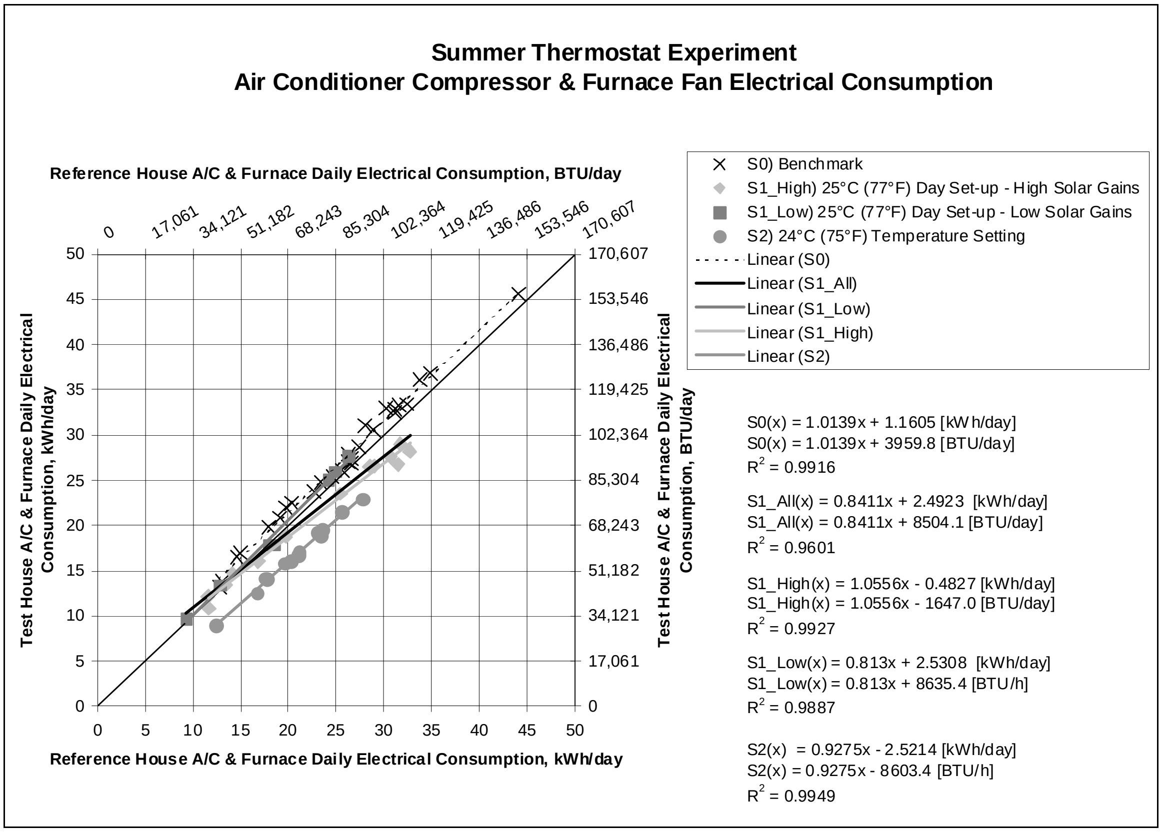

Figure 3 Summer Electrical Consumption Trends

Summer recovery times

Recovery times from set-up were directly related to the highest temperature reached by air at the location of the thermostat. This relationship is shown in Figure 4. The higher the temperature reached, the longer the recovery time. Recovery times from this 3°C (5.4°F) change in thermostat setting exceeded 7 hours on four of the test days – a time period comparable to the length of the set-up itself. These long recovery times are attributable in part to thermostat cycling. With the exception of the day with the shortest recovery time, the air conditioner cycled 3 to 5 times before fully recovering from thermostat set-up. As with recovery from set-back, this is again a feature of the thermostat's control strategy: time-based cycling as it nears the set point temperature.

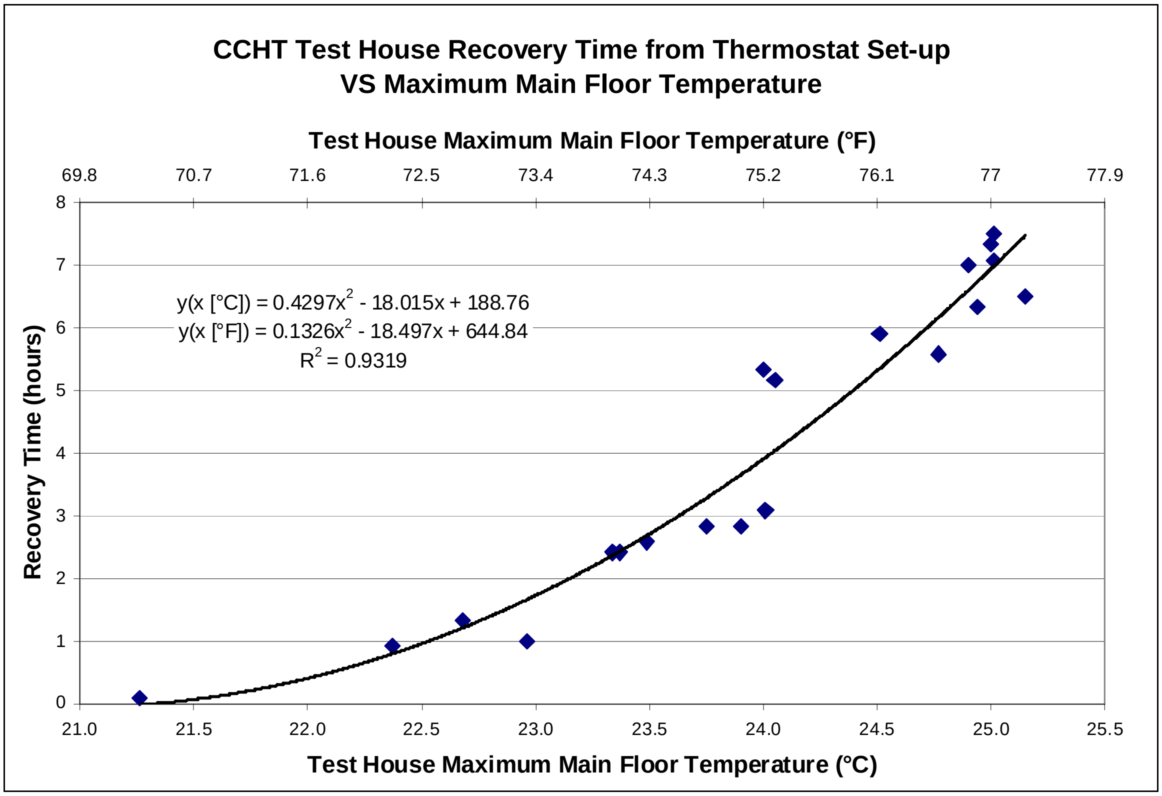

Figure 4 Summer Recovery Time VS Maximum Main Floor Temperature

House humidity

The humidity levels of a house contribute to occupant comfort and affect the perceived temperature. The longer the air conditioner runs, the more water is removed from the air in the form of condensate on the air conditioner coil. At the higher temperature setting (S2), the air conditioner ran for shorter periods of time each day, saving energy, but also increasing the humidity level in the house. Average daily house humidity levels increased from the benchmark condition by approximately 0.7 g_w/kg_{da} (0.0007 lb_w/lb_{da}), or ~4% RH at 22°C (72°F). During the thermostat set-up trials (S1), average daily humidity levels in the Test House were similar to the benchmark levels.

DISCUSSION

The EnergyStar savings calculator for programmable thermostats assumes a 3% savings per degree-Fahrenheit of setback (5.4% per degree Celcius), based on 2004 Industry data (EnergyStar 2005). Similar savings were predicted by Nelson and MacArthur (1978): an eight-hour day and night set-back of 5.6°C (10°F) would yield at minimum, a 20% savings in cold climates; while a smaller 2.8°C (5°F) setback would yield savings of just below 15% in these same regions. Measured savings from the CCHT experiments were slightly lower. A dual seven hour setback of 4°C (7.2°F) produced a seasonal savings of 10% on furnace gas consumption, while a dual seven hour setback of 6°C (10.8°F) produced a seasonal savings of 13%. Apart from the shorter duration of setbacks, 7 hours instead of 8 hours, the airtightness, insulation, and passive solar design of the R-2000 house may have contributed to the difference in measured savings, compared to previously published values.

This experiment's results are, however, far from the negligeable savings reported by Poehlman (1988) for thermostat set-back in an R-2000 home at Noble Kirk Farm. There are a few factors that distinguish the two studies and likely contribute to their differing results. First, the CCHT house is a much different creature than the Noble Kirk Farm home. Despite their similar R-2000 qualification, the CCHT Test house is much larger (210m^2 [2260 ft^2] compared to 121 m^2 [1300 ft^2]), two-stories (as opposed to a bungalow), and has a full basement (where the other has none). Additionally, due to its proximity to Lake Ontario, the climate of Hamilton, Ontario (the location of Noble Kirk Farm) is slightly milder than the climate of Ottawa, Ontario (the location of CCHT). Environment Canada data (1971-2000) indicates that the Celcius heating degree days <18°C for the two locations are 4012 and 4602 respectively (7222 and 8283 Fahrenheit degree days <64°F). Since savings from thermostat setback were shown to increase with decrease in outdoor temperature, and to be negligeable at an average outdoor temperature above 4°C (39°F), a warmer climate would result in a reduction in savings. Additionally, a smaller setback was employed by Poehlman, a 2°C (3.6°F) setback at night, and a 4°C (7.2°F) setback during the day. A smaller nighttime setback would again decrease the available savings, and help to explain the difference between the outcomes of the CCHT and Noble Kirk Farm experiments.

The results from the winter set-back experiments highlight the need for the use of "optimum start"– where the thermostat anticipates the house's response and begins heating in advance to meet the desired temperature setting at the proper time. This was not a feature of the programmable thermostats tested at CCHT, however, it is a requirement on newer Energy Star models. The 2-hour recovery time on cold days could easily be anticipated by this control strategy, increasing occupant comfort in the early evening. However, the optimum start time strategy would cause the house to spend less time at the set-back temperature, resulting in reduced savings from those recorded in this experiment.

Furnace size is a contributing factor to recovery time. Oversizing of furnaces is a common industry practice (Gusdorf, 2003). The furnaces used for this experiment were oversized, with an output of 63.5 MJ/h (60,190 BTU/h). The highest heating load measured at the CCHT twin house facility in the winter of 2002-2003 was only 33.2 MJ/h (31,470 BTU/h). Although a smaller sized furnace could heat the house effectively at a constant setpoint, it would experience more difficulty recovering from set-back temperatures, resulting in longer recovery times. Were the furnace size an exact match to the highest heating load, it would be unable to fully recover from the added load of the thermostat setback on the coldest days of winter.

Throughout both the summer and winter trials, the furnace operated in continuous circulation. This is the house's standard mode of operation, and is required to provide outdoor air via the HRV in the highly airtight R-2000 construction. In a house with looser construction, the furnace could be operated in "automatic" mode, allowing outdoor air to be obtained from natural ventilation, without the 84% efficient heat exchange of the HRV. In this type of operation, one would expect a quicker response of the house to a set-back or set-up – looser construction allowing for faster heat transfer between indoors and outdoors. More savings from thermostat set-back would be expected in these looser homes, particularly during warm winter weather with an average outdoor temperature above 4°C (39°F), where savings in the R-2000 Test House were negligible. Additionally, a slower recovery time would be expected for the same reasons – the furnace (or air conditioner) having to run longer to combat the larger heat gains (or losses) to regain the original thermostat setting. Thus, the house would spend more time at the set-back or set-up conditions, resulting in larger savings. Continuous circulation, in addition to circulating outdoor air from the HRV, also helps to distribute heat in the house. Without continuous circulation an increase in stratification would occur, creating potential for even lower surface temperatures during setback.

The coolest surface temperatures were recorded at the sill of the operable window during the setback experiments. Even at a constant 22°C (72°F) setting, these temperatures descend below the dewpoint of air at the humidity levels recommended by Canada Mortgage and Housing corporation: 30% when exterior temperatures are below –10°C (14°F). Wall surface temperatures were warmer. However, it should be noted that drywall temperatures were measured above insulated spaces, and not at the studs or at the junction between drywall sheets. Lower surface temperatures would be expected at these less insulated locations. The probability of condensation would depend on material properties and should be determined through modeling, which is outside the scope of this experiment.

Both summer thermostat strategies were accompanied by advantages and disadvantages. The energy savings from the set-up strategy were offset by the long recovery times. Even with a thermostat equipped with pre-comfort recovery, in order to return to the set temperature on hot days the thermostat would have to start its recovery roughly half-way through the set-up period. This recovery time could be reduced slightly by eliminating air conditioner cycling as it approaches the setpoint. However, without controlled cycling, the system would be more likely to overshoot the setpoint temperature, providing unnecessary excess cooling and adversely affecting comfort.

Long recovery times from summer set-up are mainly attributable to air conditioner sizing. Although the 2-ton air conditioner was effective at maintaining the house at a constant set temperature even on the hottest days, it was not effective at recovering from a 3°C (5°F) set-up, let alone a 4°C (7°F) set-up as preprogrammed into Energy Star thermostats. Central air conditioners are often sized to just meet the design cooling-load calculated, as was the CCHT air conditioner. The highest measured cooling demand during the summer of 2003 was 23.4 MJ/h (22,200 BTU/h), while the air conditioner was designed to provide 2 tons of cooling (nominal) or 25.3 MJ/h (24,000 BTU/h). A larger unit is not recommended, as it would cycle for shorter periods of time, removing less humidity from the air. However, larger sizing may be necessary if summer set-up strategies are to be implemented effectively. An additional drawback to the set-up strategy is the resulting peak in energy use late in the evening, something utilities are trying hard to minimize. For these reasons, the set-up thermostat strategy many not be the best energy saving strategy for summer.

The summer higher temperature setting results in larger savings than the set-up, and also eliminates this evening peak by maintaining the house temperature throughout the day. However, the issue of comfort is raised. Not only is the temperature in the house higher than ideally desired, but the humidity levels are also slightly increased because of the reduced air conditioner operation.

CONCLUSION

Energy savings and whole house response from three thermostat set-back strategies were examined at the CCHT twin-house facility. Despite the energy efficiency of the R-2000 Test House, thermostat set-back strategies provided up to 13% seasonal savings in furnace gas consumption and 2.3% seasonal savings in furnace electrical consumption. The highest energy savings occurred for the lowest set-back temperature (16°C [61°F]), on the days with the highest heating loads. On warmer days, savings from thermostat set-back were negligible, as the R-2000 home maintained its temperature despite the thermostat setting. On most occasions, recovery times from thermostat set-back were less than 1 hour, reaching a maximum of 2.25 hours on the coldest test day. Generally, thermostat set-back proved to be an effective and inexpensive energy saving strategy in an energy efficient home.

Two summer thermostat strategies were examined: a daytime temperature set-up and a higher temperature setting 24h per day. Air conditioner and furnace electrical savings from the set-up strategy were highly dependent on weather – days with low solar gains producing minimal savings. For the entire cooling season, savings of 11% could be expected. The set-up strategy also suffered from long recovery times, surpassing 7 hours on the hottest days. Proper implementation of a set-up strategy would require larger sizing of the air conditioning unit to reduce these recovery times. Even then, the set-up strategy would be adding to the peak electrical load experienced in the evening by utilities. Air conditioner and furnace electrical savings were more than twice as high for the higher temperature setting strategy, 23% for the entire cooling season. The downside to the higher temperature setting is occupancy comfort. Not only is the temperature higher, but indoor humidity increases due to less frequent air conditioner operation, decreasing comfort levels and increasing perceived heat. Thermostat strategies are likely not the best alternative when used on their own for reducing summer energy use.

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APPENDIX A

Table A-1 Total Daily Furnace Gas Consumption during Winter Thermostat Trials

Trials:
W1) 18°C (64°F) Night Set-back
W2) 18°C (64°F) Day and Night Set-back
W3) 16°C (61°F) Day and Night Set-back

Trial	Date	Average Outdoor Temperature		Measured Reference House Daily Furnace Gas Consumption		Measured Test House Daily Furnace Gas Consumption		Calculated Test House Daily Furnace Gas Consumption without Set-back - Based on Reference House Consumption and Benchmark Correlation		Daily Savings from Set-back Strategy
		°C	°F	MJ	BTU	MJ	BTU	MJ	BTU	%
W1	22-Nov-02	2.4	36.3	267.5	253,500	235.9	223,600	266.9	253,000	11.6
W1	23-Nov-02	-3.1	26.4	371.5	352,100	346.7	328,600	375.4	355,800	7.6
W1	24-Nov-02	0.2	32.4	318.9	302,300	295.9	280,500	320.5	303,800	7.7
W1	17-Dec-02	-10.5	13.1	372.6	353,200	351.8	333,400	376.6	356,900	6.6
W1	18-Dec-02	-9.3	15.3	351.1	332,800	342.2	324,300	354.1	335,600	3.4
W1	19-Dec-02	-4.8	23.4	429.7	407,300	411.0	389,600	436.2	413,400	5.8
W1	20-Dec-02	0.8	33.4	336.8	319,200	325.0	308,000	339.3	321,600	4.2
W1	22-Dec-02	1.0	33.8	321.4	304,600	310.7	294,500	323.1	306,200	3.9
W1	01-Jan-03	-5.2	22.6	409.5	388,100	386.8	366,600	415.1	393,400	6.8
W1	02-Jan-03	-10.3	13.5	449.9	426,400	434.6	411,900	457.3	433,400	5.0
W1	21-Jan-03	-22.3	-8.1	670.9	635,900	599.9	568,600	687.9	652,000	12.8
W1	22-Jan-03	-23.2	-9.8	759.1	719,500	698.8	662,300	780.0	739,300	10.4
W2	24-Dec-02	-6.4	20.5	302.7	286,900	279.8	265,200	303.7	287,900	7.9
W2	26-Dec-02	-6.7	19.9	401.8	380,800	355.1	336,600	407.0	385,800	12.8
W2	27-Dec-02	-7.5	18.5	471.3	446,700	411.8	390,300	479.6	454,600	14.1
W2	28-Dec-02	-2.5	27.5	377.1	357,400	337.7	320,100	381.3	361,400	11.4
W2	29-Dec-02	-3.8	25.2	287.6	272,600	275.0	260,600	287.9	272,900	4.5
W2	30-Dec-02	-10.2	13.6	483.1	457,900	421.9	399,900	492.0	466,300	14.2
W2	31-Dec-02	-3.7	25.3	440.3	417,300	383.7	363,700	447.3	424,000	14.2
W2	03-Jan-03	-7.1	19.2	487.8	462,300	418.1	396,300	496.8	470,900	15.8
W2	04-Jan-03	-3.6	25.5	399.9	379,000	349.2	331,000	405.1	384,000	13.8
W2	05-Jan-03	-3.5	25.7	342.8	324,900	315.6	299,100	345.5	327,500	8.6
W2	06-Jan-03	-4.2	24.4	376.0	356,400	336.2	318,700	380.2	360,400	11.6
W2	07-Jan-03	-10.7	12.7	412.2	390,700	382.6	362,600	418.0	396,200	8.5
W2	17-Jan-03	-17.9	-0.2	548.6	520,000	478.6	453,600	560.3	531,100	14.6
W2	18-Jan-03	-17.5	0.5	627.4	594,700	556.4	527,400	642.5	609,000	13.4
W2	19-Jan-03	-10.4	13.3	474.8	450,000	420.9	398,900	483.3	458,100	12.9
W3	25-Jan-02	-11.3	11.7	582.0	551,600	477.2	452,300	595.2	564,100	19.8
W3	26-Jan-02	-9.9	14.2	491.0	465,400	412.0	390,500	500.2	474,100	17.6
W3	27-Jan-02	-23.0	-9.4	617.4	585,200	507.0	480,500	632.1	599,100	19.8
W3	28-Jan-02	-20.2	-4.4	725.1	687,300	596.9	565,800	744.5	705,600	19.8
W3	29-Jan-02	-11.9	10.6	469.6	445,100	395.1	374,500	477.8	452,900	17.3
W3	01-Feb-03	-2.1	28.2	353.2	334,800	311.9	295,600	356.4	337,800	12.5
W3	02-Feb-03	0.3	32.5	302.0	286,200	271.9	257,700	302.9	287,100	10.2

Table A-2 Total Daily Air Conditioner Compressor and Furnace Fan Electrical Consumption during Summer Thermostat Trials

Trials:
S1) 25°C (77°F) Daytime Set-up
S2) 24°C (75°F) TemperatureSetting

Trial	Date	Average Outdoor Temperature		Total Daily Solar Radiation Incident on South-facing Vertically-mounted Pyranometer, kJ/m^2 (BTU/ft^2)		Measured Reference House Daily A/C and Furnace Electrical Consumption		Measured Test House Daily A/C and Furnace Electrical Consumption		Calculated Test House Daily A/C and Furnace Electrical Consumption without change in thermostat setting - Based on Reference House Consumption and Benchmark Correlation		Daily Savings from Strategy
		°C	°F	kJ/m^2	BTU/ft^2	kWh	BTU	kWh	BTU	kWh	BTU	%
S1	15-Jul-03	24.3	75.7	11,441	1007	31.48	107,400	26.77	91,300	33.08	112,900	19.1
S1	16-Jul-03	22.4	72.3	8,996	792	28.48	97,200	26.56	90,600	30.03	102,500	11.6
S1	17-Jul-03	21.2	70.2	10,058	886	25.42	86,700	23.52	80,300	26.94	91,900	12.7
S1	18-Jul-03	18.5	65.3	10,877	958	19.73	67,300	18.76	64,000	21.16	72,200	11.4
S1	19-Jul-03	18.7	65.7	7,269	640	17.90	61,100	17.91	61,100	19.31	65,900	7.3
S1	20-Jul-03	19.2	66.6	7,312	644	18.41	62,800	17.87	61,000	19.83	67,700	9.9
S1	05-Aug-03	24.4	75.9	11,914	1049	32.68	111,500	28.19	96,200	34.30	117,000	17.8
S1	06-Aug-03	23.1	73.6	6,733	593	24.86	84,800	25.97	88,600	26.37	90,000	1.5
S1	07-Aug-03	24.2	75.6	10,657	938	28.98	98,900	26.57	90,700	30.54	104,200	13.0
S1	08-Aug-03	24.4	75.9	12,334	1086	31.72	108,200	28.99	98,900	33.32	113,700	13.0
S1	09-Aug-03	23	73.4	6,741	594	26.27	89,600	27.71	94,600	27.80	94,900	0.3
S1	10-Aug-03	23.3	73.9	5,801	511	24.15	82,400	25.13	85,700	25.65	87,500	2.0
S1	11-Aug-03	24.3	75.7	12,650	1114	30.66	104,600	27.59	94,100	32.24	110,000	14.4
S1	24-Sep-03	15.3	59.5	13,984	1231	16.79	57,300	16.03	54,700	18.18	62,000	11.8
S1	25-Sep-03	13.9	57.0	10,090	888	14.13	48,200	14.78	50,400	15.48	52,800	4.6
S1	26-Sep-03	11.8	53.2	10,654	938	11.61	39,600	12.18	41,600	12.93	44,100	5.8
S1	27-Sep-03	17.6	63.7	3,640	321	12.77	43,600	13.45	45,900	14.11	48,100	4.6
S1	28-Sep-03	13.8	56.8	2,859	252	9.31	31,800	9.70	33,100	10.60	36,200	8.5
S1	29-Sep-03	12	53.6	14,042	1236	13.47	46,000	13.46	45,900	14.81	50,500	9.1
S1	30-Sep-03	9.3	48.7	13,745	1210	11.70	39,900	10.83	37,000	13.02	44,400	16.9
S2	21-Jul-03	20.5	68.9	5,345	471	18.94	64,600	11.95	40,800	20.36	69,500	41.3
S2	22-Jul-03	21.2	70.2	7,849	691	23.44	80,000	18.89	64,500	24.93	85,100	24.2
S2	23-Jul-03	21.2	70.2	9,136	804	25.61	87,400	21.55	73,500	27.12	92,500	20.5
S2	24-Jul-03	19.7	67.5	3,982	351	19.65	67,000	15.83	54,000	21.08	71,900	24.9
S2	25-Jul-03	22.4	72.3	12,690	1117	27.77	94,800	22.92	78,200	29.31	100,000	21.8
S2	26-Jul-03	22.2	72.0	3,605	317	21.02	71,700	16.74	57,100	22.47	76,700	25.5
S2	27-Jul-03	21.9	71.4	5,982	527	23.51	80,200	19.50	66,500	24.99	85,300	22.0
S2	28-Aug-03	14.4	57.9	11,787	1038	16.73	57,100	12.54	42,800	18.12	61,800	30.8
S2	29-Aug-03	16.3	61.3	3,311	292	12.40	42,300	8.96	30,600	13.73	46,800	34.7
S2	30-Aug-03	15.7	60.3	14,060	1238	17.60	60,100	14.17	48,400	19.01	64,900	25.5
S2	31-Aug-03	16.4	61.5	15,781	1390	20.22	69,000	16.14	55,100	21.66	73,900	25.5
S2	01-Sep-03	19.1	66.4	12,234	1077	21.11	72,000	17.05	58,200	22.57	77,000	24.4
S2	02-Sep-03	18.1	64.6	16,054	1414	23.10	78,800	19.19	65,500	24.58	83,900	21.9
S2	03-Sep-03	17.4	63.3	8,035	708	17.78	60,700	14.12	48,200	19.19	65,500	26.4