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The Effects of Thermostat Setback and Setup on Seasonal Energy Consumption, Surface Temperatures, and Recovery Times at the CCHT Twin House Research Facility

Marianne M. Manning **Mike C. Swinton, PE**
Member ASHRAE

Frank Szadkowski **John Gusdorf** **Ken Ruest**

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 the examination of not only energy savings but also of whole-house performance. During the thermostat experiments, important factors that affect occupant comfort were explored, including air temperature recovery time from setback and setup, house surface temperatures during winter setback, solar effects, and summer house humidity, giving a broad picture of the effects of thermostat setback/setup in a typical R-2000 home.

INTRODUCTION

The Canadian Centre for Housing Technology (CCHT) is jointly operated by the National Research Council Canada, Natural Resources Canada, and Canada Mortgage and Housing Corporation. CCHT is home to a unique facility of identical two-story 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 more than 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 at 50 Pa (1.0 lb/ft^2), slow decreases in indoor temperature during a setback were anticipated, and so the benefits of thermostat setback 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 setup were expected. The instrumented facility not only allowed 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 factors evaluated. This paper presents the results of this study.

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 US climates. Pilati estimated that with the proper incentives, homeowners would make changes in home thermostat settings that could reduce US energy consumption by approximately 4.4%. Nelson and MacArthur (1978) modeled daytime and nighttime thermostat setback strategies, revealing furnace gas savings ranging from 15% to 25%. The use of thermostat setback in energy-efficient houses has also been explored. Poehlman et al. (1988) concluded that setback 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 et al. (2005), Maheshwari et al. (2000), Raja et al. (2001), and Armstrong et

Marianne M. Manning is a technical officer at the Institute for Research in Construction (IRC), National Research Council Canada, Ottawa, Ontario. **Mike C. Swinton** is a senior research officer at IRC and research manager of Canadian Centre for Housing Technology Research Committee, Ottawa. **Frank Szadkowski** and **John Gusdorf** are project officers, Building Energy Technologies program, Natural Resources Canada, Ottawa. **Ken Ruest** is a senior researcher in housing technology, Canada Mortgage and Housing Corporation, Ottawa.

al. (1992a, 1992b), have centered on energy savings in commercial buildings rather than the residential sector.

As energy costs increase, the lifestyle changes described by Pilati and other researchers in the 1970s 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 toward 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 setback and cooling setup program (ENERGY STAR® 2005). Required preprogramming includes both daytime and nighttime temperature adjustment. An acceptable program is listed in Table 1.

Table 1. ENERGY STAR® Acceptable Setpoint Times and Temperature Settings (ENERGY STAR® 2005)

		Setpoint Temperature	
Setting	Time	Heat	Cool
Wake	6:00 a.m.	21°C (70°F)	26°C (78°F)
Day	8:00 a.m.	17°C (62°F)	29°C (85°F)
Evening	6:00 p.m.	21°C (70°F)	26°C (78°F)
Sleep	10:00 p.m.	17°C (62°F)	28°C (82°F)

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.

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 affect 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 (child) lightbulbs.

Approach

The thermostat setting study took place in the winter of 2002–2003 and the summer of 2003. A side-by-side testing

Table 2. CCHT Research House Specifications

Feature	Details
Construction standard	R-2000
Livable area	210 m^2 (2260 ft^2), 2 stories
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 vapor 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 subfloor
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 at 50 Pa (1.0 lb/ft^2)
Furnishing	Unfurnished

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 setback or summer setup. Benchmarking also occurred in between strategies and following the experiment to ensure that house performance remained unchanged.

Three different setback 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 setup, 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 experimental strategy are listed in the last two columns of Table 3.

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/h when at the 50% load condition.

Both houses were equipped with a gas furnace at 80% efficiency (measured) with a standard permanent split capacitor 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 SEER-12 (nominal) air-conditioning unit with 2 ton capacity provided cooling. A heat recovery ventilator (HRV) at 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 at 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 are on the first floor; eleven supply registers and five return grilles are on the second floor; and three supply registers and a single return grille are 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, in accordance with 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 five-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 surfaces of three separate windows at the center 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 windows. 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 excep-

Table 3. Test Days and Outdoor Temperatures

Strategy	Winter: Setback Temperature from 22°C (72°F) Summer: Setup 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 setback	18°C (64°F)	23:00–6:00	12	–27 to 4 (–17 to 39)
W2—18°C (64°F) day and night setback	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 setback	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 setup	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.