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NRCC-50859

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2008-11-13

A version of this document is published in / Une version de ce document se trouve dans:
Building Physics Symposium, Lueven, Belgium, October 29-31, 2008, pp. 1-5.

National Research Council Canada
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Thermostat setback effect in whole building performance

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Keywords: HAM, hygrothermal, Whole building, HAMFitPlus, thermostat, indoor humidity

Summary.

One of the strategies for conservation of energy in buildings is to use a programmable thermostat. In a heating season, the heating demand decreases as the operative indoor temperature is lowered. In this paper, a whole building hygrothermal model (HAMFitPlus) is used to analyze the energy saving that can be obtained in adopting three different thermostat setting schemes in a real occupied residential house. Moreover, the effect of these energy saving options in the indoor relative humidity and moisture performance of a building are discussed. In the first thermostat-setting scheme, the indoor temperature is maintained constant at 21^{o}C at all time (no set-back). In the second thermostat-setting scheme, the indoor temperature is maintained at 21^{o}C from 7:00 to 21:00 h, and then setback to 17^{o}C for the remaining hours (21:00 to 7:00 h). The third thermostat-setting scheme is similar to the second scheme except that the increment of the indoor temperature from 17 to 21^{o}C is done in three steps (1.5, 1.5 and 1^{o}C increments at 5, 6 and 7 h, respectively) as opposed to the second option where a single step (4^{o}C increment) is used. An integrated analysis of energy, indoor humidity and durability of the building suggest that implementation of thermostat with temperature setback reduces heating energy consumption by as much as 4.42%, in the case of single-step up, and 3.62%, in case of multiple-steps up, when compared to the case with a constant temperature setting (reference case). This energy saving strategy, however, results in high indoor relative humidity fluctuations.

1. INTRODUCTION

The three aspects of building design: hygrothermal performance of building enclosure, indoor humidity level and energy efficiency are interrelated and have to be considered simultaneously for optimized building design. Ignoring the inter-related and coupled effects of the three design aspects and exclusively dealing with only one aspect of the building design may result in poor overall building performance. For example, ignoring the moisture buffering effect of the interior layer of the building enclosure in indoor humidity predictions and moisture effect on the energy calculation may lead to over or under sizing of HVAC equipments and result in the associated problems on building enclosure moisture performance and occupants' comfort and health. There is a growing interest in an integrated building performance analysis as documented in the recently completed internation research project called IEA[**]Annex 41. In this paper, a whole building hygrothermal model called HAMFitPlus[1] is used to study the effect of thermostat setback schemes in the overall performance of a resedential building. The model considers the building as a system and deals with the dynamic heat, air and moisture (HAM) interactions among building envelope components, indoor environment and mechanical systems; and simulanteiously predicts the energy consumption, indoor humdity and moisture response of building envelope components in an integrated manner. The whole building hygrothermal model (HAMFitPlus) is successfully benchmarked[1] against internationally published analytical, numerical and experimental test cases[2,3].

[**] International Energy Agency

2. REFERENCE BUILDING

The reference building considered in this paper is an occupied house in Carmacks, which is located in the northwestern part of Canada in Yukon Territories at latitude of 62° 7' north and longitude of 136° 11' west and has an elevation of 543 m above sea level. As part of a NRC-IRC research project[4] the indoor and outdoor conditions of the house were monitored for four weeks, January 19th to February 20th, 2006. The average outdoor temperature during the monitoring period is –19°C while the indoor temperature is fairly constant at 20°C. In addition to the indoor and outdoor temperature and relative humidity the dimension, orientation, building enclosure components including windows areas and orientations, air-tightness, occupancy and mechanical systems of the house were documented. The house is occupied by five people in the day time and six at night. It has a floor area of 81.9 m^2 and volume of 196 m^3. In this paper, all this information including the measured outdoor boundary conditions are used in the whole building hygrothermal simulation of the house.

3. THERMOSTAT SETBACK SCHEMES

One of the strategies for conservation of energy is decreasing the operative indoor temperature, which thereby reduces the heating demand. The house considered here is assumed to be occupied throughout the day. Hence, the only time the indoor temperature can be reduced is during sleeping time (21:00-7:00 h), when the occupants use additional insulation (blankets) to maintain their thermal comfort. Figure 1 shows three thermostat settings considered here. The first thermostat setting belongs to a reference case where the indoor temperature is maintained constant at 21°C at all time (no set-back). In the second thermostat-setting scheme, the indoor temperature is maintained at 21°C from 7:00 to 21:00 h, and then setback to 17°C for the remaining hours (21:00 to 7:00 h). This scheme is referred to as single-step up since the indoor temperature increases in a single step from 17 to 21°C at 7:00 h. The third thermostat-setting scheme is similar to the second scheme except that the increment of the indoor temperature from 17 to 21°C is done in three steps (1.5, 1.5 and 1°C increments at 5, 6 and 7 h, respectively) as opposed to the second option where a single step (4°C increment) is used. The third option is referred to as multiple-steps up.

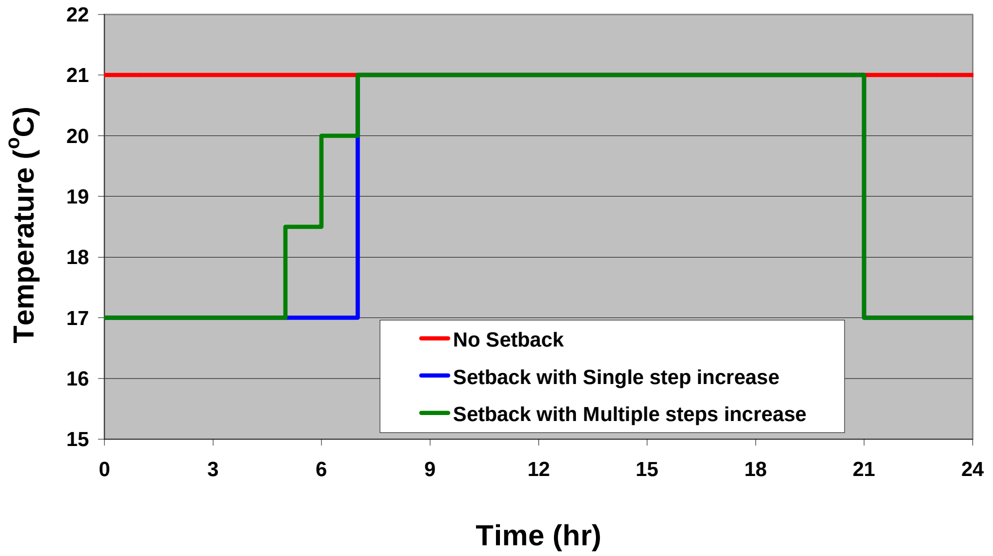

Figure 1 Thermostat setting schemes for a typical day.

4. WHOLE BUILDING HYGROTHERMAL SIMULATION RESULTS

4.1 Energy consumption

Energy analysis of the three thermostat-setting schemes suggests that implementation of thermostat with temperature setback reduces heating energy consumption by as much as 4.42% (single-step up case) when compared to the case with a constant temperature setting (reference case). Adoption of the third thermostat-setback scheme (multiple-steps up) results in 3.62% heating energy saving compared to the reference case. Although a relatively higher energy saving is obtained by choosing the single-step rather than multiple-steps up scheme, the peak energy demand at the transition of indoor temperature from 17 to 21^{o}C is significantly higher in the single-step up scheme. Figure 2 shows a typical daily energy consumption profile of the house. The energy demand in the reference case is nearly uniform throughout the day. But in cases with thermostat setback schemes, the heating demand is significantly high in the morning (7:00 h), and in the evening (21:00–23:00 h) no heating is required. The peak energy demands in the cases of single step and multiple-step schemes are 21.01 and 13.16 kW, respectively, while in the reference case is only 7.43 kW. These results imply that indoor temperature control with thermostat setback can decrease energy consumption, but may require a heating system with a higher heating capacity to maintain the desired indoor temperature quickly. In the case considered here, the heating capacity of the system needs to be increased by 77 and 183% of the reference case if the multiple-step and single-step schemes are chosen, respectively. Among the thermostat-setback scheme considered, the multi-step scheme might be preferable since it represents a compromise between the energy saving and equipment size.

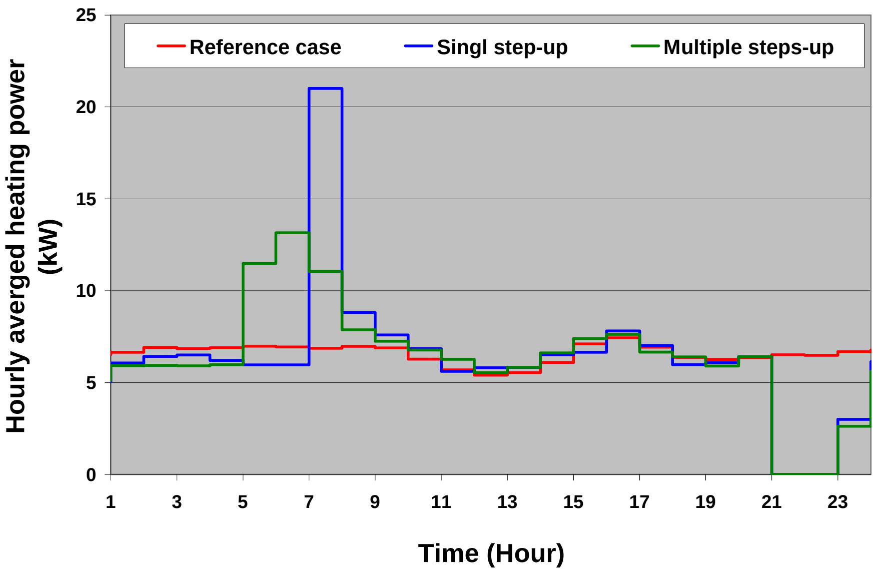

Figure 2 Typical day energy consumption of the house under different thermostat setback scheme.

4.2 Indoor humdity

HAMFitPlus solves energy and indoor humidity balance equations simultaneously, and therefore, the effect of energy upgrade on the indoor humidity and durability of the envelope can be investigated at the same time. Figure 3 shows the indoor relative humidity profiles of the house for the three thermostat settings for the 30 days simulation periods. The cases with thermostat-setback options, single- and multiple steps up, have fluctuating profiles. In cases with thermostat-setback, the indoor relative humidity reaches the maximum during the period when the temperature setback is effective. The differences in the daily peaks of relative humidity between the cases with and without thermostat-setback options are significant, reaching as high as 12%.

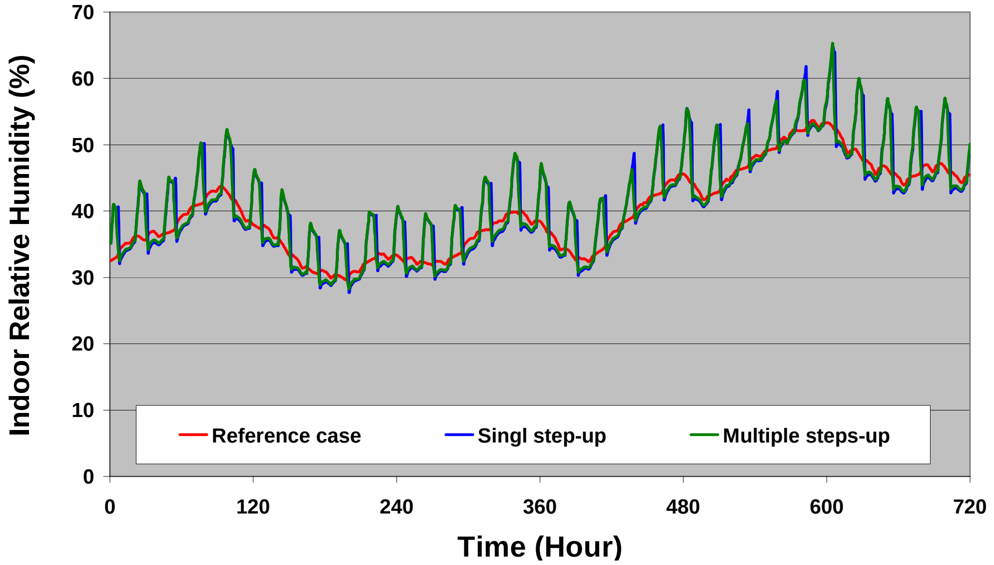

Figure 3 Indoor relative humidity profiles of the house for the three thermostat setback schemes.

4.3 Moisture in building envelope component

Although the thermostat setback improves the energy efficiency of the house as demonstrated here, the effect of high indoor relative humidity fluctuation, as the consequence of thermostat setback, on the durability of building envelope components also need consideration. This is because the low indoor temperature coupled with unchanged moisture supply results in more condensation on windows surfaces and building envelope components. As the whole building hygrothermal simulations results suggest the amount of condensate on the window surfaces increases by 2.10 and 1.82% for the single-step and multi-steps-up cases, respectively, compared to the reference case. Moreover, the simulation results show that the relative humdity at the back of the interior gypsum board increases by about 3% from the reference case during the night time when the thermostat setback period is on. These cyclic moisture loadings with short amplitude and frequency may have an effect on the moisture performance of of the component.

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