CANADA'S GREEN PLAN
LE PLAN VERT DU CANADA

SUMMARY OF C-2000 BUILDING SIMULATION

PREPARED FOR:

The CANMET Energy Technology Centre (CETC)
Energy Technology Branch, Energy Sector
Department of Natural Resources Canada
Ottawa, Ontario, K1A 0E4
CANMET Contract No. 23440-94-1018
May, 1994, Revised June 1994

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Reprint February 11, 1997

CITATION

Caneta Research Inc., *Summary of C-2000 Building Simulation.* DSS Contract No. 23440-94-1018. The CANMET Energy Technology Centre (CETC), Energy Technology Branch, Energy Sector, Department of Natural Resources Canada, Ottawa, Ontario, 1994, (51 pages).

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NOTE

Funding for this project was provided by the Government of Canada under the Green Plan.

Catalogue No. M91-7/307-1994E
ISBN 0-662-22579-1

RÉSUMÉ

CANMET a demandé que soit fait le présent projet dans le cadre du Programme des bâtiments commerciaux performants (C-2000).

Le projet avait pour but de documenter la simulation énergétique réalisée au cours de l'élaboration des Critères techniques C-2000. Dans l'ensemble, 41 simulations DOE-2 furent réalisées à partir de situations hypothétiques représentant des bureaux et des immeubles à résidences multiples dans le but d'établir les critères énergétiques C-2000 et de démontrer comment répondre aux exigences énergétiques établies.

Le rapport porte sur chacune de ces simulations : il présente des données détaillées, et des données numériques et graphiques sur l'utilisation énergétique simulée. Les renseignements seront utiles aux équipes de conception C-2000, aux équipes, aux chercheurs aux concepteurs de Défi IDÉES et autres intervenants de l'industrie énergétique du bâtiment.

Executive Summary

This project was commissioned by CANMET as part of its C-2000 Program for Advanced Commercial Buildings.

The purpose of the project was to document the energy simulation performed during the development of the C-2000 Technical Criteria. A total of 41 DOE-2 simulations were performed on hypothetical office and multi-unit residential buildings to establish the C-2000 energy criteria and to demonstrate how the energy criteria could be met.

This report documents each of these simulations: detail ed input data are given as well as numerical and graphical data on the simulated energy use. The information will be of use to C-2000 design teams, IDEAS teams, researchers, building designers and others interested in energy use in buildings.

SUMMARY OF C-2000 BUILDING SIMULATIONS

1. INTRODUCTION

Forty-one DOE-2 simulations of office and multi-unit residential buildings were performed to establish the C-2000 energy targets (see Section 4.1 of the C-2000 Program Requirements, October 15, 1993). The base energy consumption of the buildings was defined using ASHRAE 90.1-1989 as a guideline. Descriptions of the changes to the base buildings and the results of the simulations are documented in this report.

Although the purpose of these simulations was to determine the C-2000 energy criteria and to demonstrate that the criteria could be met, the results are of interest to building designers, researchers, and analysts as well as the C-2000 design teams.

Annual energy consumptions are presented in two forms: metered energy and energy cost. Metered energy is the energy content of the gas, oil, and electricity used by the building, expressed in common energy units, and normalized by the floor area (MJ/m^2). Energy cost is determined using local oil, gas, electricity consumption, and electricity demand charges and is normalized by the floor area ($\$/m^2$).

2. THE APPROACH

All energy analyses were conducted on hypothetical buildings using DOE-2.1D. Six buildings were defined with each located in a different Canadian city. The floor areas and shapes are typical of current construction; shapes that are advantageous from an energy perspective were not selected because a building's shape is often dictated by lot sizes.

Ideally, simulations would have been performed for numerous buildings at many locations across the country, and each energy-conservation measure (ECM) would have been tested independently as well as in combination with others. Thus, the impact of each ECM would have been known for each building at each location. Such an effort, however, was not possible due to budgetary and time constraints. So six buildings were analyzed (three office buildings and three multi-unit residential (MUR) buildings), each located in a single location, and the ECMs were grouped into packages.

ASHRAE/IES Standard 90.1-1989 for Energy Efficient Design of New Buildings Expect Low-Rise Residential Buildings (called ASHRAE 90.1) was selected as the base case reference for C-2000 energy targets. ASHRAE 90.1 was selected because it is known to industry, it is being used in building codes (Vancouver, Toronto, and Ontario), and the Canadian National Energy Code had not yet been released.

Each of the six hypothetical buildings was made to conform with the ASHRAE 90.1 prescriptive requirements (the System/Component Method) for envelope, lighting, and HVAC systems. The energy consumption of each building was determined by simulation following the Energy Cost Budget (ECB) Method, given in Section 13 of ASHRAE 90.1. The ECB method prescribes internal loads (office equipment, appliances, people), schedules (occupancy, lighting, office equipment, appliances, HVAC, hot water), infiltration rates, and setpoint temperatures. These simulations resulted in the ASHRAE 90.1 energy consumption for each building.

The results of the ASHRAE 90.1 simulations were analyzed and the first package of energy conservation measures (ECMs) was selected. The goal was to improve all building components which had a significant impact on energy use by applying proven technologies. In the office buildings the lighting power density was lowered, the glazings were improved, insulation was added to the walls and roofs, infiltration was reduced, and HVAC equipment efficiencies were improved. In the MUR buildings insulation was added to the walls and roofs, infiltration was reduced, the lighting levels were reduced, appliance energy use was reduced, the glazings were improved, heat-recovery ventilators were added to each unit, and space heating and cooling equipment efficiencies were improved. The HVAC systems in all buildings were unchanged apart from efficiency improvements. These buildings, called the advanced normal variants, were simulated. Some of the buildings were simulated again with the advanced normal variant package, but with different glazing areas as it was felt that in some cases the ASHRAE 90.1 prescribed glazing areas were not typical. The goal was to achieve energy efficiency without compromising aesthetics or functionality.

The results of the advanced normal variant simulations were analyzed and the second package of ECMs was selected. The goal was to further improve all the building components that had a significant impact on energy use by applying currently available and emerging technologies. In the office buildings the lighting power density was lowered even further, photoelectrically-controlled daylight dimming was added to the perimeter lights, Smartbar controllers were installed on personal computers, external shading was incorporated to reduce excess solar gains, and solid-state controllers were added for the elevators. HVAC system improvements in the offices included ground-source heat pumps in two buildings, and improved boiler and chiller efficiencies in the third. In the MUR buildings appliance energy use was lowered further, motion sensors were added for hall lights, and solid-state controllers were installed for the elevators. HVAC system improvements in the MURs included the addition in all three buildings of ground-source heat pumps; domestic hot water was heated by use of refrigerant desuperheaters coupled with high-efficiency gas-fired storage heaters. These buildings, called the hot variants, were simulated. Some of the buildings were resimulated at the hot variant level to also determine the impact of different glazing areas.

Some innovative cooling systems were analyzed as a third package for the buildings at the hot variant level in an attempt to achieve further energy savings. In the office buildings a packaged rooftop desiccant system was simulated in one building while water side economizers, or strainer cycles, were simulated in the other two. In the MUR buildings strainer cycles were simulated in the two larger buildings. The small MUR, which had not generally had mechanical cooling in previous runs, was not simulated with an innovative cooling system. The strainer cycles in the offices were installed on central VAV systems while the MURs were four pipe fan coil systems. Since these systems were not the systems used in all buildings at the hot variant level, there was a need to simulate the building with and without the strainer cycle to illustrate its impact.

A final, fourth package of ECMs were modelled in the office buildings. Starting with the hot variant level, all three office buildings had recirculation of supply air eliminated such that the system provided 100% outdoor air. The 100% outdoor air ventilation system was accompanied with central heat recovery.

Although all of the simulations were performed using DOE-2.1D, some elements of some ECMs were beyond the scope of this tool. In two situations energy accounting was performed external to DOE-2.1D: pumps circulating fluid from ground heat exchangers to the buildings and ventilation fan energy use when water-loop heat pump supply fans cycled with compressor operation. During the simulations two idealizations were made: heat recovery effectiveness did not vary with outdoor air temperature and return temperatures from ground-coupled systems did not vary enough to impact on heat pump compressor performance.

3. THE BUILDINGS

Three hypothetical office buildings–small, medium, and large–and three hypothetical multi-unit residential (MUR) buildings–small, medium, and large–were defined for the energy simulations. Each of the six buildings was located in a different city; the location defined the weather and the prescriptive requirements for the ASHRAE 90.1 reference. The geometry of each building was selected to reflect current construction practices.

The small office building was located in Halifax, was two storeys, had 2970 m^2 (32 000 ft^2) of floor area and was representative of low-rise construction. The medium office building was located in Edmonton, had four storeys, 7430 m^2 (80 000 ft^2) of floor area and was representative of construction on large suburban lots. The large office building was located in Vancouver, was ten storeys, with underground parking and had 13380 m^2 (144 000 ft^2) of floor area. This building was representative of high-rise construction on urban lots.

The small MUR was located in Montréal, was three storeys, had 47 units and a floor area of 4460 m^2 (48 000 ft^2). This building was representative of walk-up housing. The medium MUR was located in Winnipeg, was six storeys with underground parking underneath the building, had 95 units, a floor area of 9500 m^2 (102 312 ft^2) and was representative of mid-rise apartments. The large MUR was located in Toronto, was 20 storeys with underground parking, had 139 units and a floor area of 13940 m^2 (150 000 ft^2). This building was representative of high-rise condominiums in urban areas.

The building envelope consisted of spandrel glass curtain walls for all three office buildings, and common face brick for all three MURs. Occupancy levels and scheduling were as dictated by ASHRAE 90.1 and did not change with ECM level.

4. RESULTS

The attachment presents the results of the ASHRAE 90.1 simulations and the simulations performed with the various ECM packages. For each building a description of specific changes included in each ECM package is given. Accompanying each description is a graph showing energy consumed by end-use (normalized to area), a graph showing source energy consumed by end-use (normalized to area - source energy is defined in the C-2000 criteria as the sum of purchased fuel energy and three times purchased electrical energy), a graph showing energy cost by fuel type (normalized to area), and a table detailing building characteristics for each simulation.

5. CONCLUSIONS

Office Buildings

Twenty-six simulations were performed on office buildings varying in size from 2970 m^2 to 13380 m^2. When designed to meet the ASHRAE 90.1-1989 Standard the buildings used an average of about 650 MJ/m^2. The advanced normal variant level of buildings and system improvements reduced the energy consumption by about 40%. The adoption of the hot variant level of improvements yielded energy savings of 60% to 70% of the ASHRAE 90.1 base case values.

Increasing the window to wall ratio increased overall energy consumption. The effect of increased solar gain on space heating energy and the increased daylighting opportunities were more than offset by the impact on space cooling and the increased heat loss through the windows.

The innovative cooling variants used in the two larger office buildings reduced space cooling energy by up to 32% while only having a small effect on overall building energy use. The desiccant system used in the small office building increased energy consumption dramatically, but had little impact on overall energy cost.

The impact of using 100% outdoor air with heat recovery varied with building location. In a very cold climate, such as Edmonton, overall building energy use increased, while in more moderate climates the overall energy use decreased.

Multi-Unit Residential Buildings

Fifteen simulations were performed on multi-unit residential buildings varying in size from 4460 m^2 to 13940 m^2. With ASHRAE 90.1 used as a guideline, the buildings averaged about 740 MJ/m^2 in overall energy consumption. The advanced normal variant group of building and system changes reduced the energy consumption in the building by 50% to 65%. With the hot variant level of improvements energy savings were as high as 75% of the ASHRAE 90.1 base case.

As with the office buildings, reducing the window to wall ratio in the multi-unit residential building had a positive impact on building energy use.