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
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NOTE

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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.

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

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

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.

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.

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.

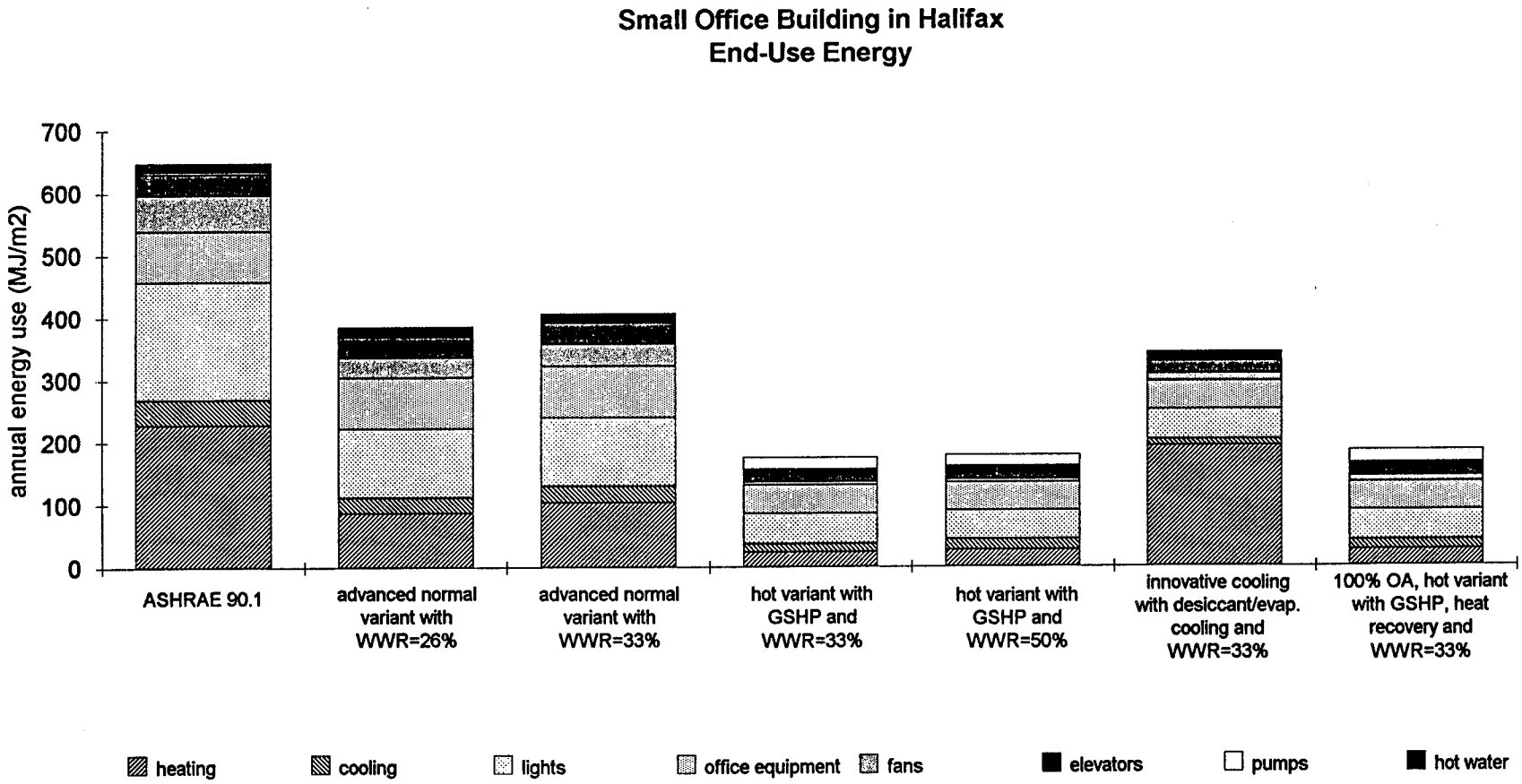
The impact of using 100% outdoor air with heat recovery varied with building location. In a very cold climate, such as Edmonton, overall building energy use increased, while in more moderate climates the overall energy use decreased.

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.

RESULTS


Small Office Building in Halifax
End-Use Energy
annual energy use (MJ/m2)
700
600
500
400
300
200
100
0
ASHRAE 90.1
advanced normal variant with WWR=26%
advanced normal variant with WWR=33%
hot variant with GSHP and WWR=33%
hot variant with GSHP and WWR=50%
innovative cooling with desiccant/evap. cooling and WWR=33%
100% OA, hot variant with GSHP, heat recovery and WWR=33%
heating
cooling
lights
office equipment
fans
elevators
pumps
hot water

SMALL OFFICE BUILDING IN HALIFAX

Seven simulations were performed on the small office building. The ASHRAE 90.1 simulation resulted in an annual energy use of 648 MJ/m^2.

Two simulations were performed at the advanced normal variant level, one with a window to wall ratio of 26%, the other at 33%. Changes from the ASHRAE 90.1 run included:

- lighting power reduced by 42%
- wall and roof insulating values improved by 190% and 225% respectively
- infiltration reduced by almost 50%
- a small improvement in rooftop cooling efficiency
- an improvement in windows to foam-vinyl, tinted, argon filled, triple glazing (with a low-e coating on the inside) with metal spacers from vinyl, bronze coated, double glazing with metal spacers.

These simulations resulted in about a 40% decrease in energy use from the base case. The advanced normal variant simulated with the lower window to wall ratio had a 5% lower annual energy use primarily due to lower space heating energy.

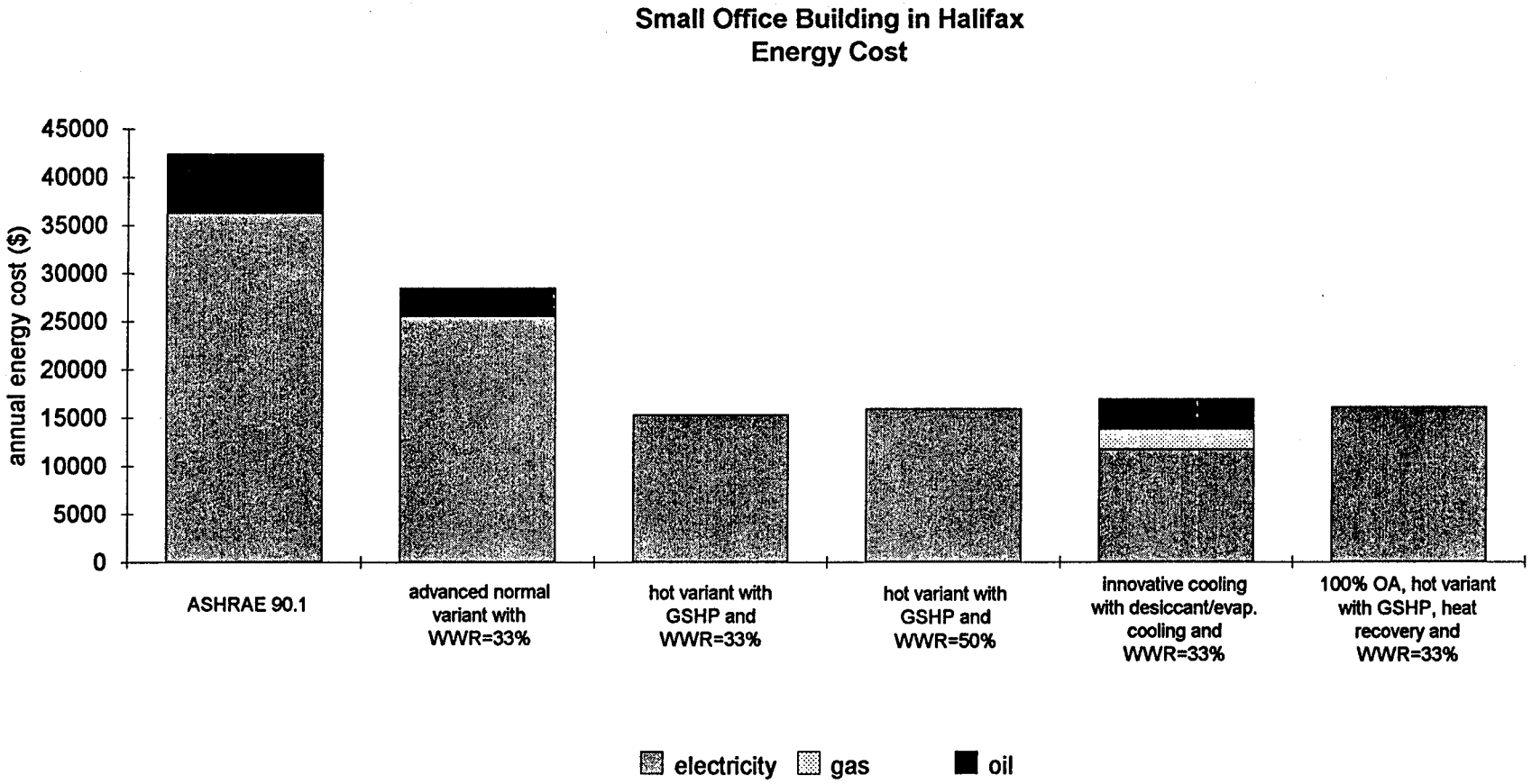
Two simulations were performed at the hot variant level, again with a difference in window to wall ratios. Changes relative to the advanced normal variant included:

- a 40% reduction in lighting power
- the addition of insulated metal spacers on the windows (the tint coating was removed from windows facing north)
- the addition of external shading on south facing windows
- a 40% reduction in power demand of the elevators
- the replacement of the packaged VAV system with a ground-source heat pump system that also satisfied the hot water load through desuperheating.

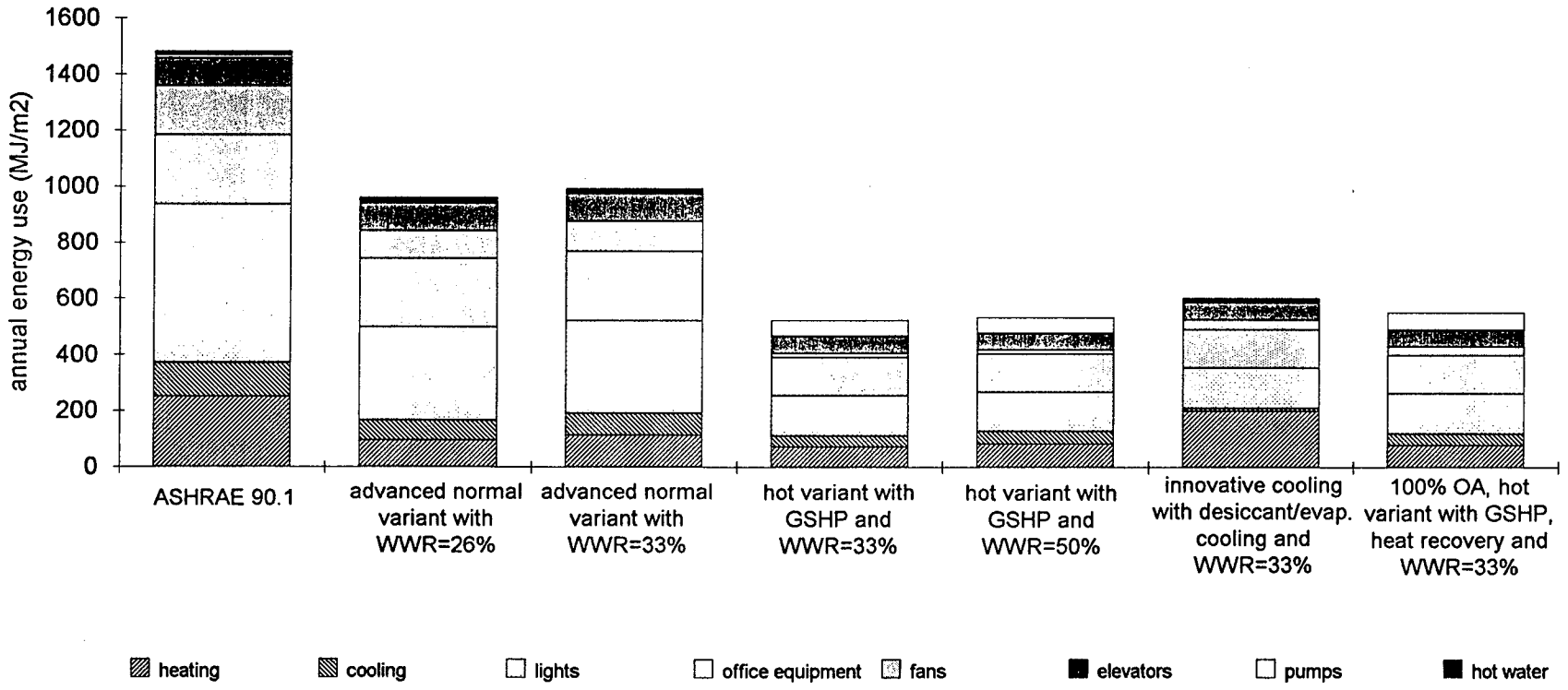
The hot variant cases consumed less than half the energy of the advanced normal variant cases. Again, the case with the lower window to wall ratio showed a marginal benefit in overall performance. Compared to the ASHRAE 90.1 base case, savings of up to 73% of energy were obtained.

One simulation was performed at the innovative cooling level, with a window to wall ratio of 33%. The ground-source heat pump system of the hot variant was replaced with a natural gas-fired, packaged desiccant / evaporative cooling system. Hot water was supplied by a high efficiency oil-fired storage heater.

One simulation was also performed at the 100% outdoor air level. The hot variant system was altered to eliminate recirculated air. Heat recovery was assumed to be able to recover 80% of the sensible and latent heat of the exhaust air. The impact of this change was a 6% increase in building energy, relative to the hot variant, primarily due to increased fan energy.


Small Office Building in Halifax
Energy Cost
annual energy cost ($)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
ASHRAE 90.1
advanced normal variant with WWR=33%
hot variant with GSHP and WWR=33%
hot variant with GSHP and WWR=50%
innovative cooling with desiccant/evap. cooling and WWR=33%
100% OA, hot variant with GSHP, heat recovery and WWR=33%
electricity
gas
oil

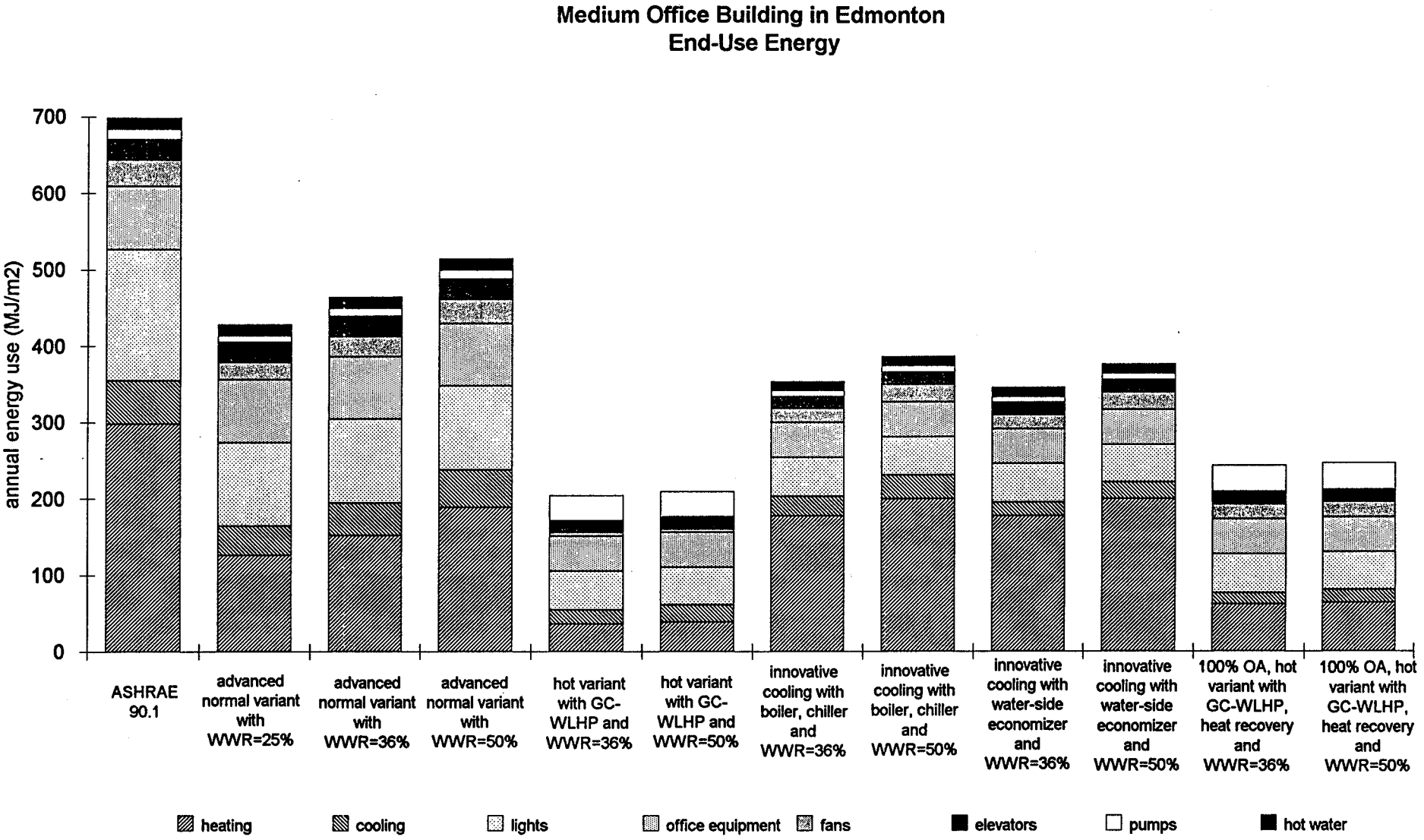
Small Office Building in Halifax
Source Energy



Source Energy is equal to the sum of purchased fuel energy and three times purchased electrical energy.

SMALL OFFICE BUILDING IN HALIFAX

	ASHRAE 90.1	advanced normal variant with WWR=26%	advanced normal variant with WWR=33%	hot variant with GSHP and WWR=33%	hot variant with GSHP and WWR=50%	innovative cooling with desiccant/ evap. cooling and WWR=33%	100%OA hot variant with GSHP, heat recovery, and WWR=33%
lights	18.5 W/m²	10.8 W/m²	10.8 W/m²	6.5 W/m²	6.5 W/m²	6.5 W/m²	6.5 W/m²
				daylight dimmers	daylight dimmers	daylight dimmers	daylight dimmers
	schedule A	schedule A	schedule A	schedule A	schedule A	schedule A	schedule A
office equipment	8.1 W.m²	8.1 W.m²	8.1 W.m²	8.1 W.m²	8.1 W.m²	8.1 W.m²	8.1 W.m²
	schedule A	schedule A	schedule A	schedule B	schedule B	schedule B	schedule B
occupants	4.8 W/m²	4.8 W/m²	4.8 W/m²	4.8 W/m²	4.8 W/m²	4.8 W/m²	4.8 W/m²
	schedule C	schedule C	schedule C	schedule C	schedule C	schedule C	schedule C
wall	2.44 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	2.71 RSI	8.80 RSI	8.80 RSI	8.80 RSI	8.80 RSI	8.80 RSI	8.80 RSI
glazing	0.339 RSI	0.734 RSI	0.734 RSI	0.839 RSI	0.839 RSI	0.839 RSI	0.839 RSI
	SC=0.65	SC=0.25	SC=0.25	SC=0.25 (E,S,W)	SC=0.25 (E,S,W)	SC=0.25 (E,S,W)	SC=0.25 (E,S,W)
				SC=0.65(N)	SC=0.65(N)	SC=0.65(N)	SC=0.65(N)
	WWR=26%	WWR=26%	WWR=33%	WWR=33%	WWR=50%	WWR=33%	WWR=33%
				shading on south	shading on south	shading on south	shading on south
infiltration	0.19 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule F	schedule F	schedule F	schedule F	schedule F	schedule F	schedule F
HVAC Base System	packaged roof top VAV	packaged roof top VAV	packaged roof top VAV	ground source heat pumps	ground source heat pumps	packaged desiccant system	ground source heat pumps
Cooling	air economizer	air economizer	air economizer	EER=18.8 COP=3.86	EER=18.8 COP=3.86	direct and indirect evaporative cooling	EER=18.8 COP=3.86
	direct-expansion air-cooled chiller EER=8.9	direct-expansion air-cooled chiller EER=9.6	direct-expansion air-cooled chiller EER=9.6				100% outdoor air 80% sensible and latent heat recovery
Heating	hydronic perimeter reheat oil-fired boiler 83% combustion efficiency	hydronic perimeter reheat oil-fired boiler 83% combustion efficiency	hydronic perimeter reheat oil-fired boiler 83% combustion efficiency			hydronic perimeter reheat oil-fired boiler 83% combustion efficiency	
	schedule E	schedule E	schedule E	schedule E	schedule E	schedule E	schedule E
elevators				60% of base case	60% of base case	60% of base case	60% of base case
hot water	oil-fired storage heater 83% combustion efficiency	oil-fired storage heater 83% combustion efficiency	oil-fired storage heater 83% combustion efficiency	100% by ground-source desuperheating	100% by ground-source desuperheating	oil-fired storage heater 95% combustion efficiency	100 by ground-source desuperheating
	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²
	schedule D	schedule D	schedule D	schedule D	schedule D	schedule D	schedule D


Medium Office Building in Edmonton
End-Use Energy
annual energy use (MJ/m2)
700
600
500
400
300
200
100
0
ASHRAE 90.1
advanced normal variant with WWR=25%
advanced normal variant with WWR=36%
advanced normal variant with WWR=50%
hot variant with GC-WLHP and WWR=36%
hot variant with GC-WLHP and WWR=50%
innovative cooling with boiler, chiller and WWR=36%
innovative cooling with boiler, chiller and WWR=50%
innovative cooling with water-side economizer and WWR=36%
innovative cooling with water-side economizer and WWR=50%
100% OA, hot variant with GC-WLHP, heat recovery and WWR=36%
100% OA, hot variant with GC-WLHP, heat recovery and WWR=50%
heating
cooling
lights
office equipment
fans
elevators
pumps
hot water

MEDIUM OFFICE BUILDING IN EDMONTON

Twelve simulations were performed on the medium office building. The ASHRAE 90.1 simulation resulted in an annual energy use of 698 MJ/m^2.

Three simulations were performed at the advanced normal variant level, with window to wall ratios of 25%, 36% and 50%. Changes from the ASHRAE 90.1 run included:

- lighting power reduced by 36%
- wall and roof insulating values improved by 130% and 170% respectively
- infiltration reduced by almost 50%
- an 18% improvement in chiller efficiency
- an improvement in windows with foam-vinyl, green tinted, argon filled, triple glazing with metal spacers instead of vinyl, bronze coated, double glazing with metal spacers.

The advanced normal variant simulated with the lowest window to wall ratio had the lowest annual energy use primarily due to lower heating energy. This change resulted in 39% less energy consumed than the ASHRAE 90.1 base case.

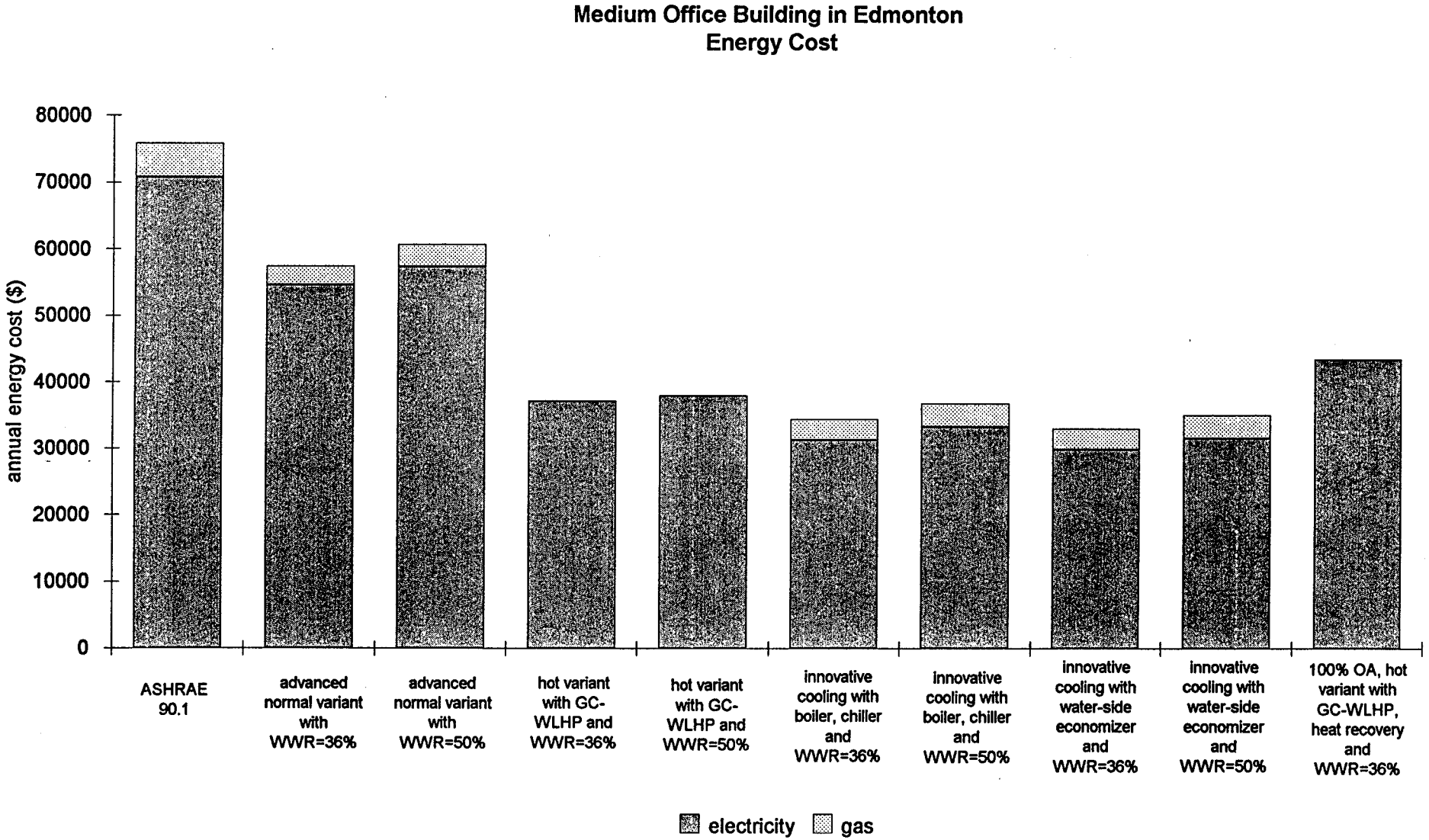
Two simulations were performed at the hot variant level, with window to wall ratios of 36% and 50%. Changes relative to the advanced normal variant included:

- a 40% reduction in lighting power
- the addition of insulated metal spacers on the windows (the green tint coating was removed from windows facing north)
- the addition of external shading on south facing windows
- a 40% reduction in power demand of the elevators
- the replacement of the central VAV system with a ground-coupled water-loop heat pump system that satisfied the hot water load through desuperheating.

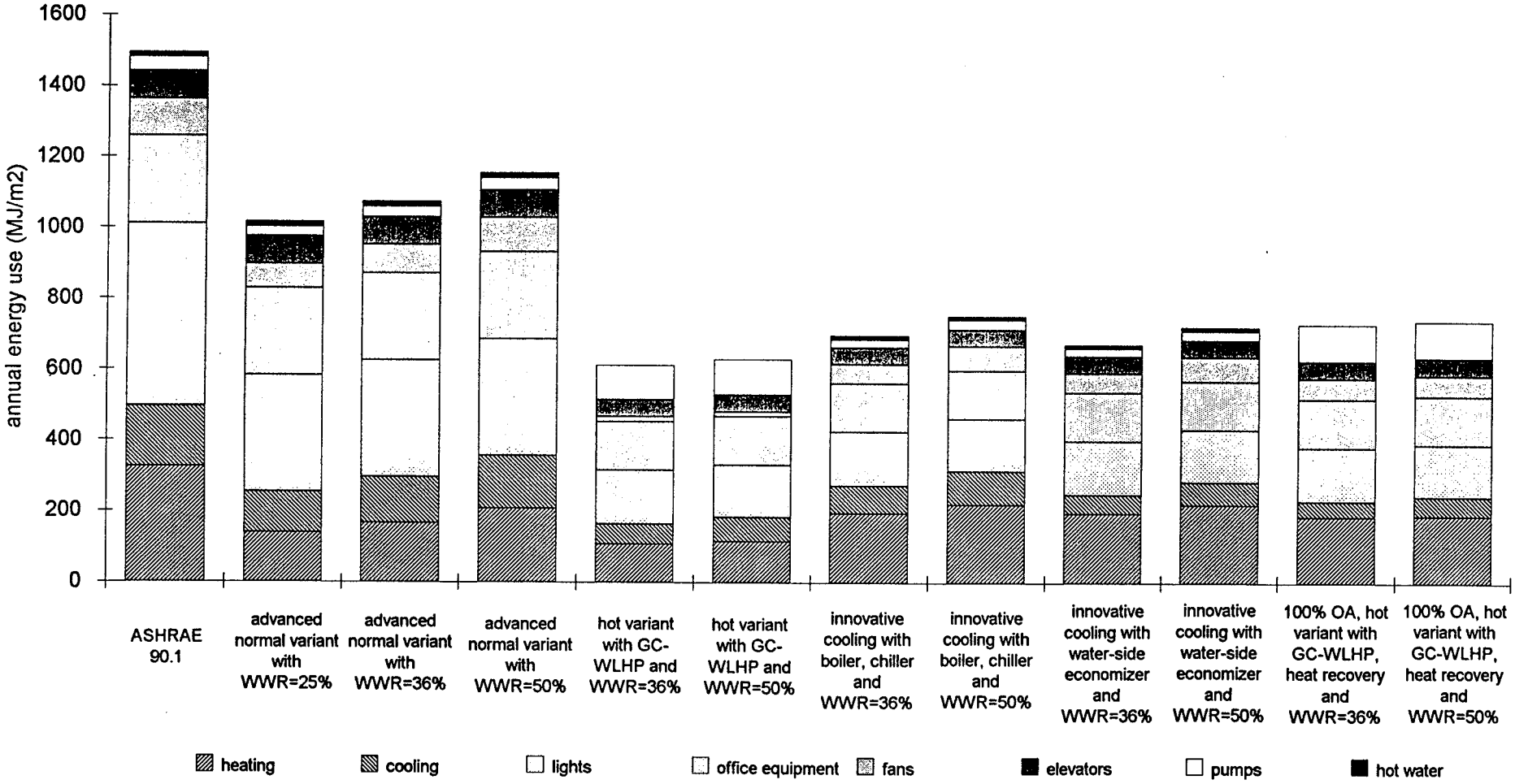
The simulation with the lower window to wall ratio showed a 56% lower annual energy use than the advanced normal variant with the same glazing, and a 70% savings compared to the ASHRAE 90.1 base case.

Four simulations were performed at the innovative cooling level, again with window to wall ratios of 36% and 50%. The ground-source heat pump system of the hot variant was replaced with the central VAV system of the advanced normal variant. The first two simulations provided a reference for the addition of a strainer cycle in the other two. Only a 2% to 3% reduction in building energy, but a 32% reduction in space cooling energy, was achieved.

Two simulations were performed at the 100% outdoor air level. The hot variant system was altered to eliminate recirculated air. Heat recovery was assumed to recover 80% of the sensible and latent heat of the exhaust air. Although space cooling energy was reduced, these simulations had an 18% to 19% greater annual energy use than the hot variant, due to an increased space heating load.


Medium Office Building in Edmonton
Energy Cost
annual energy cost ($)
80000
70000
60000
50000
40000
30000
20000
10000
0
ASHRAE 90.1
advanced normal variant with WWR=36%
advanced normal variant with WWR=50%
hot variant with GC-WLHP and WWR=36%
hot variant with GC-WLHP and WWR=50%
innovative cooling with boiler, chiller and WWR=36%
innovative cooling with boiler, chiller and WWR=50%
innovative cooling with water-side economizer and WWR=36%
innovative cooling with water-side economizer and WWR=50%
100% OA, hot variant with GC-WLHP, heat recovery and WWR=36%
electricity
gas

Medium Office Building in Edmonton
Source Energy



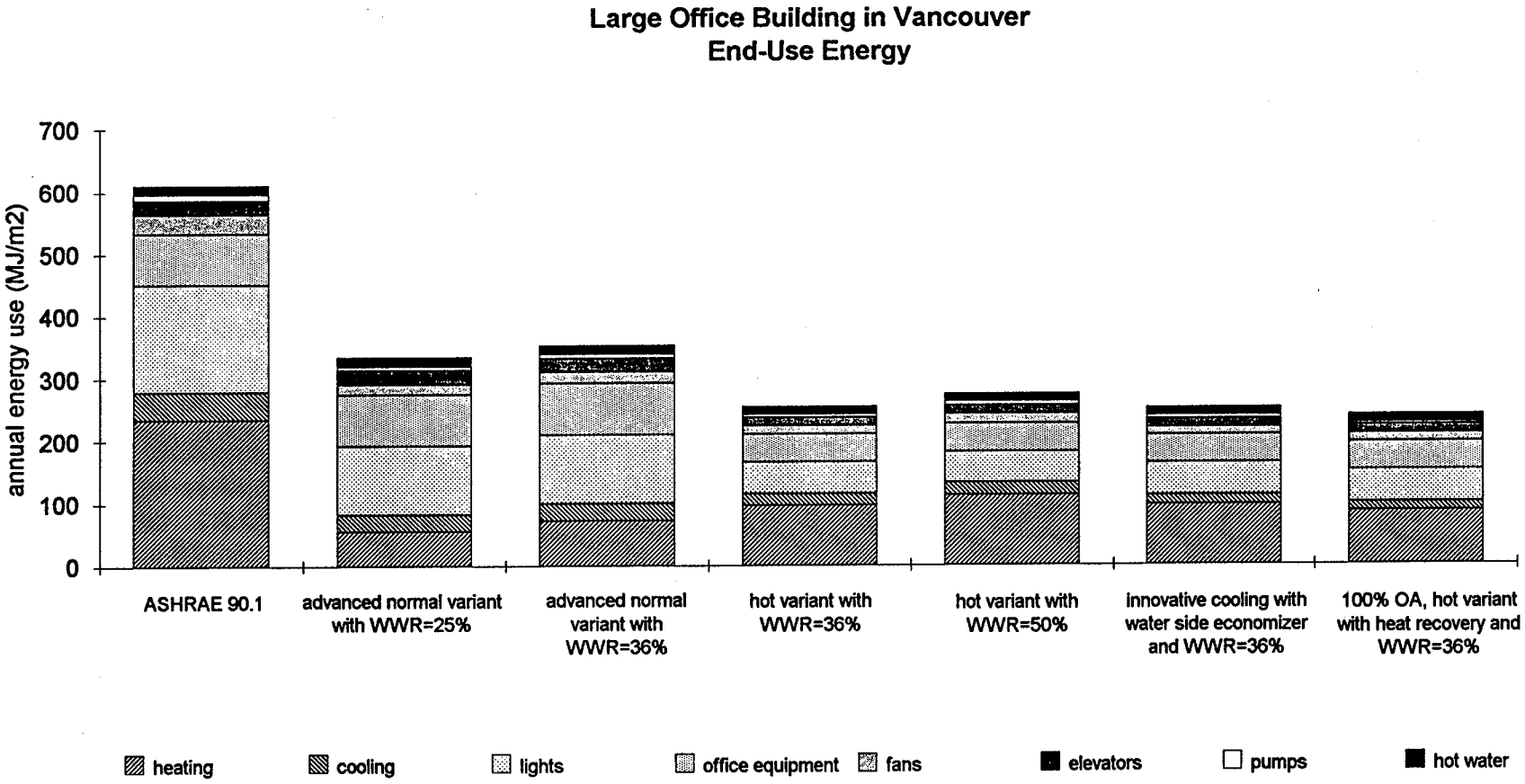
Source Energy is equal to the sum of purchased fuel energy and three times purchased electrical energy.

MEDIUM OFFICE BUILDING IN EDMONTON (cont'd)

	innovative cooling, chiller with WWR=36%	innovative cooling, chiller with WWR=50%	innovative cooling, water-side economizer WWR=36%	innovative cooling, water-side economizer with WWR=50%	100% OA hot variant GC-WLHP WWR=36%	100% OA hot variant GC-WLHP WWR=50%
lights	6.46 W/m²	6.46 W/m²	6.46 W/m²	6.46 W/m²	6.46 W/m²	6.46 W/m²
	daylight dimmers	daylight dimmers	daylight dimmers	daylight dimmers	daylight dimmers	daylight dimmers
	schedule A	schedule A	schedule A	schedule A	schedule A	schedule A
office equipment	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²
	schedule B	schedule B	schedule B	schedule B	schedule B	schedule B
occupants	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²
	schedule C	schedule C	schedule C	schedule C	schedule C	schedule C
wall	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI
glazing	0.839 RSI	0.839 RSI	0.839 RSI	0.839 RSI	0.839 RSI	0.839 RSI
	SC=0.35 (E,S,W)	SC=0.35 (E,S,W)	SC=0.35 (E,S,W)	SC=0.35 (E,S,W)	SC=0.35 (E,S,W)	SC=0.35 (E,S,W)
	SC=0.65 (N)	SC=0.65 (N)	SC=0.65 (N)	SC=0.65 (N)	SC=0.65 (N)	SC=0.65 (N)
	WWR=36%	WWR=50%	WWR=36%	WWR=50%	WWR=36%	WWR=50%
	shading on south	shading on south	shading on south	shading on south	shading on south	shading on south
infiltration	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule F	schedule F	schedule F	schedule F	schedule F	schedule F
HVAC Base System	central VAV	central VAV	central VAV	central VAV	ground coupled water loop heat pump	ground coupled water loop heat pump
Cooling	air economizer	air economizer	water-side economizer	water-side economizer		
	chiller, cooling tower EER=15.0	chiller, cooling tower EER=15.0	chiller, cooling tower EER=15.0	chiller, cooling tower EER=15.0	100% OA with 80% sensible and latent heat recovery	100% OA with 80% sensible and latent heat recovery
Heating	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	EER=18.8 COP=3.68	EER=18.8 COP=3.68
	schedule E	schedule E	schedule E	schedule E	schedule E	schedule E
elevators	60% of base case	60% of base case	60% of base case	60% of base case	60% of base case	60% of base case
hot water	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	100% by ground source system-desuperheating	100% by ground source system-desuperheating
	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²
	schedule D	schedule D	schedule D	schedule D	schedule D	schedule D

MEDIUM OFFICE BUILDING IN EDMONTON

	ASHRAE 90.1	advanced normal variant with WWR=25%	advanced normal variant with WWR=36%	advanced normal variant with WWR=50%	hot variant with GC-WLHP & WWR=36%	hot variant with GC-WLHP & WWR=50%
lights	16.90 W/m²	10.76 W/m²	10.76 W/m²	10.76 W/m²	6.46 W/m²	6.46 W/m²
					daylight dimmers	daylight dimmers
	schedule A	schedule A	schedule A	schedule A	schedule A	schedule A
office equipment	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²
	schedule A	schedule A	schedule A	schedule A	schedule B	schedule B
occupants	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²
	schedule C	schedule C	schedule C	schedule C	schedule C	schedule C
wall	3.03 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	2.71 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI
glazing	0.339 RSI	0.734 RSI	0.734 RSI	0.734 RSI	0.839 RSI	0.839 RSI
	SC=0.65 (N,E,S,W)	SC=0.35 (N,E,S,W)	SC=0.35 (N,E,S,W)	SC=O.35 (N,S,E,W)	SC=O.35 (E,S,W)	SC=O.35 (E,S,W)
					SC=0.65 (N)	SC=0.65 (N)
	WWR=25%	WWR=25%	WWR=36%	WWR=50%	WWR=36%	WWR=50%
					shading on south	shading on south
infiltration	0.19 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule F	schedule F	schedule F	schedule F	schedule F	schedule F
HVAC Base System	central VAV	central VAV	central VAV	central VAV	ground coupled water loop heat pump	ground coupled water loop heat pump
Cooling	air economizer	air economizer	air economizer	air economizer	ground-coupled heat pump system	ground-coupled heat pump system
	chiller, cooling tower EER=13.0	chiller, cooling tower EER=15.0	chiller, cooling tower EER=15.0	chiller, cooling tower EER=15.0	EER=18.8 COP=3.68	EER=18.8 COP=3.68
Heating	hydronic perimeter reheat gas-fired boiler 80% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency
	schedule E	schedule E	schedule E	schedule E	schedule E	schedule E
elevators					60% of base case	60% of base case
hot water	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 77% thermal efficiency	100% by ground source system-desuperheating	100% by ground source system-desuperheating
	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²
	schedule D	schedule D	schedule D	schedule D	schedule D	schedule D


Large Office Building in Vancouver
End-Use Energy
annual energy use (MJ/m2)
700
600
500
400
300
200
100
0
ASHRAE 90.1
advanced normal variant with WWR=25%
advanced normal variant with WWR=36%
hot variant with WWR=36%
hot variant with WWR=50%
innovative cooling with water side economizer and WWR=36%
100% OA, hot variant with heat recovery and WWR=36%
heating
cooling
lights
office equipment
fans
elevators
pumps
hot water

LARGE OFFICE BUILDING IN VANCOUVER

Seven simulations were performed on the large office building. The ASHRAE 90.1 simulation resulted in an annual energy use of 613 MJ/m^2.

Two were performed at the advanced normal variant level, with window to wall ratios of 25% and 36%. Changes from the ASHRAE 90.1 run included:

- lighting power reduced by 36%
- wall and roof insulating values improved by 270% and 250%, respectively
- infiltration reduced by almost 50%
- a 20% improvement in chiller efficiency
- an improvement in windows with foam-vinyl, tinted, argon filled, triple glazing with metal spacers replacing windows with vinyl, clear, double glazing with metal spacers.

The advanced normal variant simulated with the lower window to wall ratio had a 6% lower annual energy use than the other primarily due to a 24% savings in heating energy. This simulation had a 45% savings in energy when compared to the ASHRAE 90.1 base case.

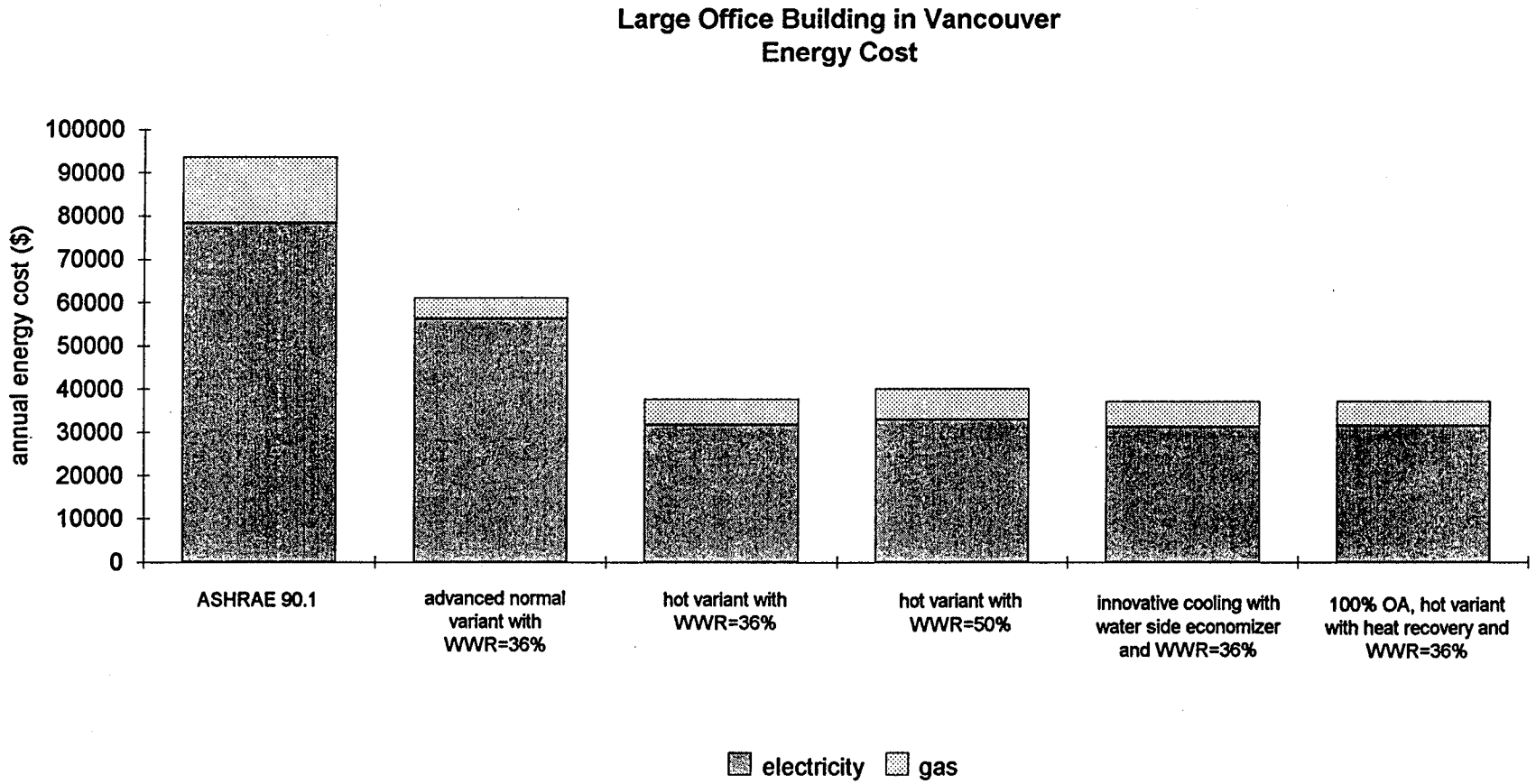
Two large office simulations were performed at the hot variant level, with the same window to wall ratios as above. Changes relative to the advanced normal variant included:

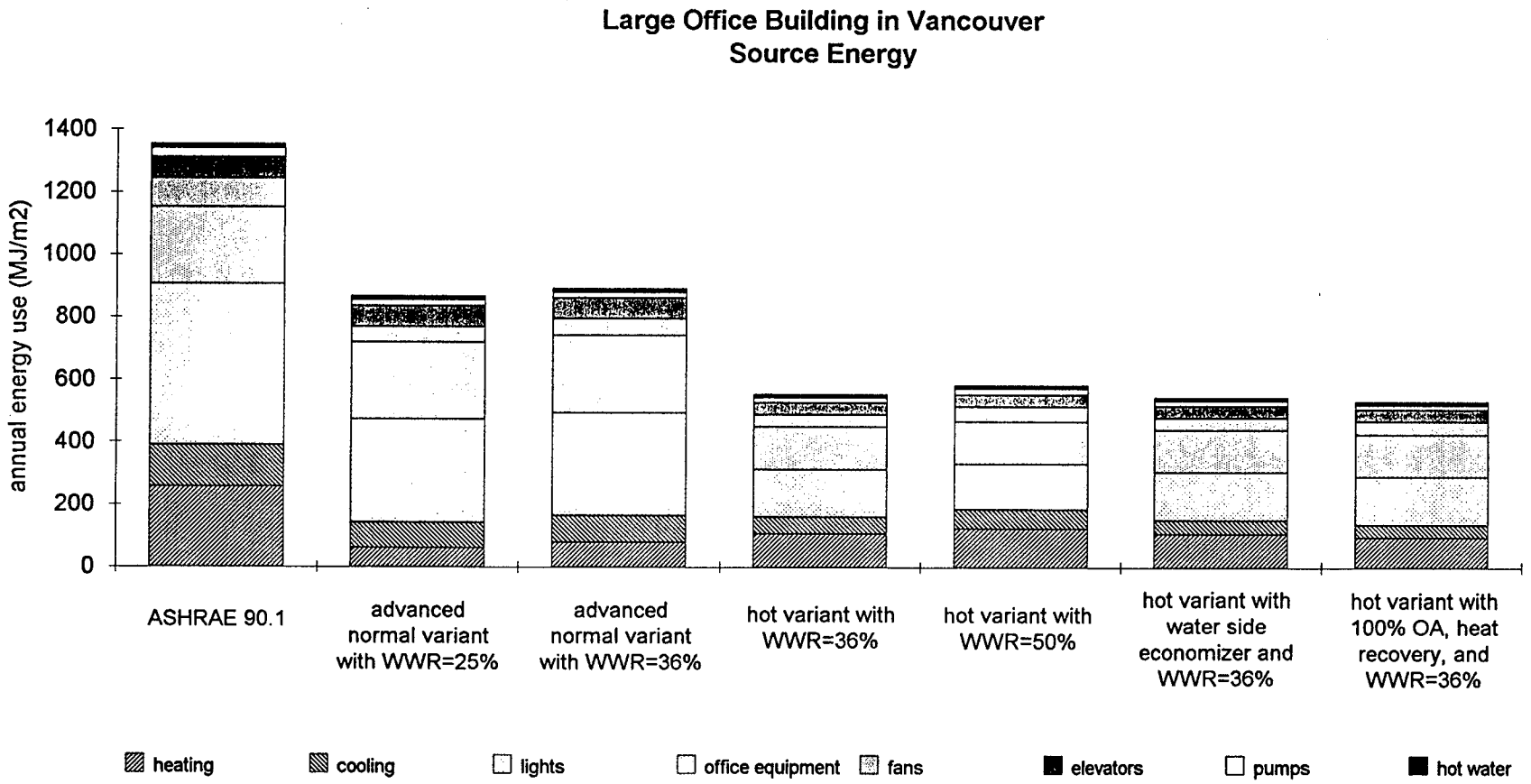
- a 40% reduction in lighting power
- the addition of insulated metal spacers on the windows (the tint coating was removed from windows facing north)
- the addition of external shading on south facing windows
- a 40% reduction in power demand of the elevators
- a 23% increase in the thermal efficiency of the gas-fired storage water heaters.

The hot variant simulations resulted in over 20% savings in annual energy use, when compared with the advanced normal variant, and almost 60% savings when compared with the ASHRAE 90.1 base case.

One simulation was performed at the innovative cooling level with a window to wall ratio of 36%. A strainer cycle was added to the cooling tower of the chiller, resulting in a 17% reduction in space cooling energy.

One simulation was performed at the 100% outdoor air level. The hot variant system was altered to eliminate recirculated air, with heat recovery assumed to recover 80% of the sensible and latent heat of the exhaust air. This simulation resulted in a 6% savings in energy use, relative to the hot variant, primarily due to a 12% reduction in space heating energy and a 19% reduction in space cooling energy due to a lower ventilation load. With heat recovery the 100% outdoor air imposed a lower ventilation load than would be the case at ASHRAE 62 levels.

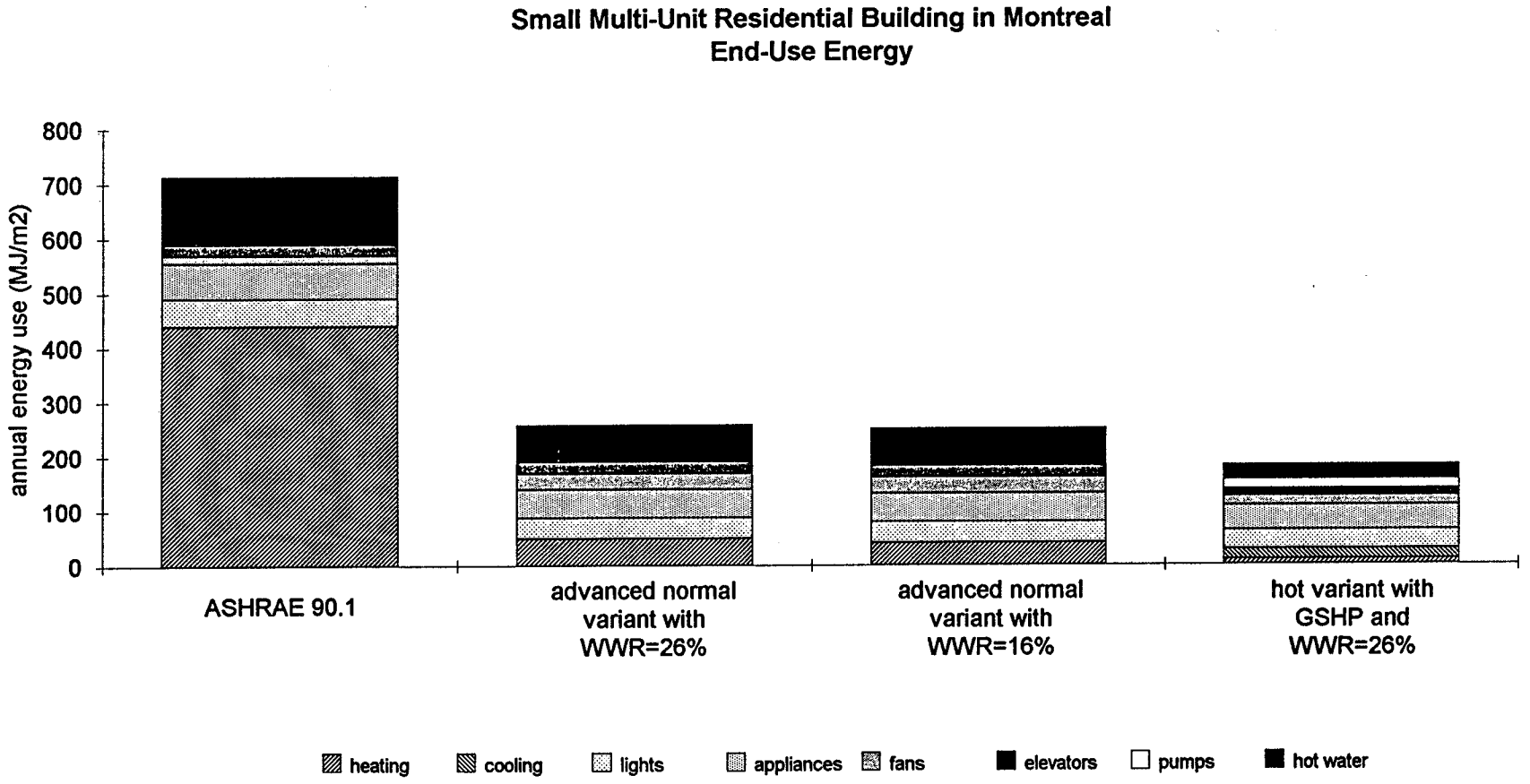

Large Office Building in Vancouver
Energy Cost
annual energy cost ($)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
ASHRAE 90.1
advanced normal variant with WWR=36%
hot variant with WWR=36%
hot variant with WWR=50%
innovative cooling with water side economizer and WWR=36%
100% OA, hot variant with heat recovery and WWR=36%
electricity
gas



Source Energy is equal to the sum of purchased fuel energy and three times purchased electrical energy.

LARGE OFFICE BUILDING IN VANCOUVER

	ASHRAE 90.1	advanced normal variant with WWR=25%	advanced normal variant with WWR=36%	hot variant with WWR=36%	hot variant with WWR=50%	innovative cooling with water side economizer WWR=36%	100%OA hot variant with HR WWR=36%
lights	16.9 W/m²	10.76 W/m²	10.76 W/m²	6.46 W/m²	6.46 W/m²	6.46 W/m²	6.46 W/m²
				daylight dimmers	daylight dimmers	daylight dimmers	daylight dimmers
	schedule A	schedule A	schedule A	schedule A	schedule A	schedule A	schedule A
office equipment	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²	8.07 W/m²
	schedule A	schedule A	schedule A	schedule B	schedule B	schedule B	schedule B
occupants	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²	4.84 W/m²
	schedule C	schedule C	schedule C	schedule C	schedule C	schedule C	schedule C
wall	1.91 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	2.07 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI	7.34 RSI
glazing	0.244 RSI	0.734 RSI	0.734 RSI	0.839 RSI	0.839 RSI	0.839 RSI	0.839 RSI
	SC=0.65 (N,E,S,W)	SC=0.20 (N,E,S,W)	SC=0.20 (N,E,S,W)	SC=0.20 (E,S,W)	SC=0.20 (E,S,W)	SC=0.20 (E,S,W)	SC=0.20 (E,S,W)
				SC=0.65(N)	SC=0.65(N)	SC=0.65(N)	SC=0.65(N)
	WWR=25%	WWR=25%	WWR=36%	WWR=36%	WWR=50%	WWR=36%	WWR=36%
				shading on south	shading on south	shading on south	shading on south
infiltration	0.19 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule F	schedule F	schedule F	schedule F	schedule F	schedule F	schedule F
HVAC Base System	central VAV	central VAV	central VAV	central VAV	central VAV	central VAV	central VAV
Cooling	air economizer	air economizer	air economizer	air economizer	air economizer	water side economizer	air economizer
	chiller, cooling tower EER=14.3	chiller, cooling tower EER=17.1	chiller, cooling tower EER=17.1	chiller, cooling tower EER=17.1	chiller, cooling tower EER=17.1	chiller, cooling tower EER=17.1	100% OA 80% heat recovery
Heating	hydronic perimeter reheat gas-fired boiler 80% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency	hydronic perimeter reheat gas-fired boiler 95% combustion efficiency
	schedule E	schedule E	schedule E	schedule E	schedule E	schedule E	schedule E
elevators				60% of base	60% of base	60% of base	60% of base
hot water	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency
	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²	2.05 W/m²
	schedule D	schedule D	schedule D	schedule D	schedule D	schedule D	schedule D


Small Multi-Unit Residential Building in Montreal
End-Use Energy
annual energy use (MJ/m2)
800
700
600
500
400
300
200
100
0
ASHRAE 90.1
advanced normal variant with WWR=26%
advanced normal variant with WWR=16%
hot variant with GSHP and WWR=26%
heating
cooling
lights
appliances
fans
elevators
pumps
hot water

SMALL MULTI-UNIT RESIDENTIAL BUILDING IN MONTREAL

Four simulations were performed on the small multi-unit residential building. The ASHRAE 90.1 simulation resulted in an annual energy use of 714 MJ/m^2.

Two simulations were performed at the advanced normal variant level, one with a window to wall ratio of 26%, the other at 16%. Changes from the ASHRAE 90.1 run included:

- lighting power reduced by 25%
- a 20% reduction in household appliance energy use
- wall and roof insulating values improved by 160% and 70% respectively
- infiltration reduced by almost 50%
- a 19% increase in gas-fired boiler efficiency
- the addition of heat recovery ventilators at 80% effectiveness to the suites
- a 30% reduction in hot water loads
- a 23% increase in gas-fired DHW boiler efficiency
- an improvement in windows to foam-vinyl, argon filled, triple glazing (low-e coating on inside) with metal spacers from vinyl, bronze coated, double glazing with metal spacers.

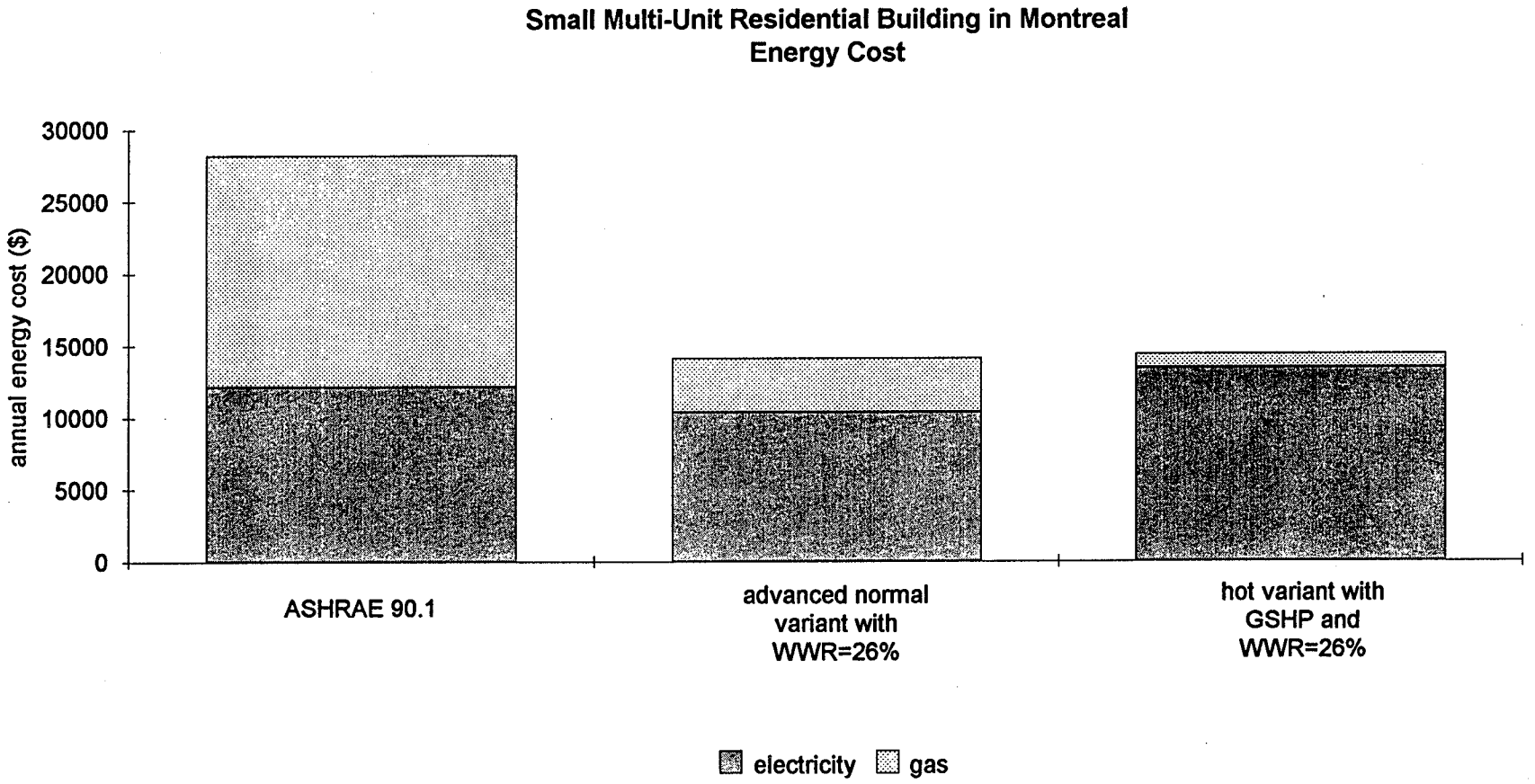
The advanced normal variant with the lower window to wall ratio had a 3% lower annual energy use than the other primarily due to a 16% lower space heating energy. Compared to the ASHRAE 90.1 base case, this simulation resulted in a 65% savings in energy use.

One simulation was performed at the hot variant level. Changes relative to the advanced normal variant included:

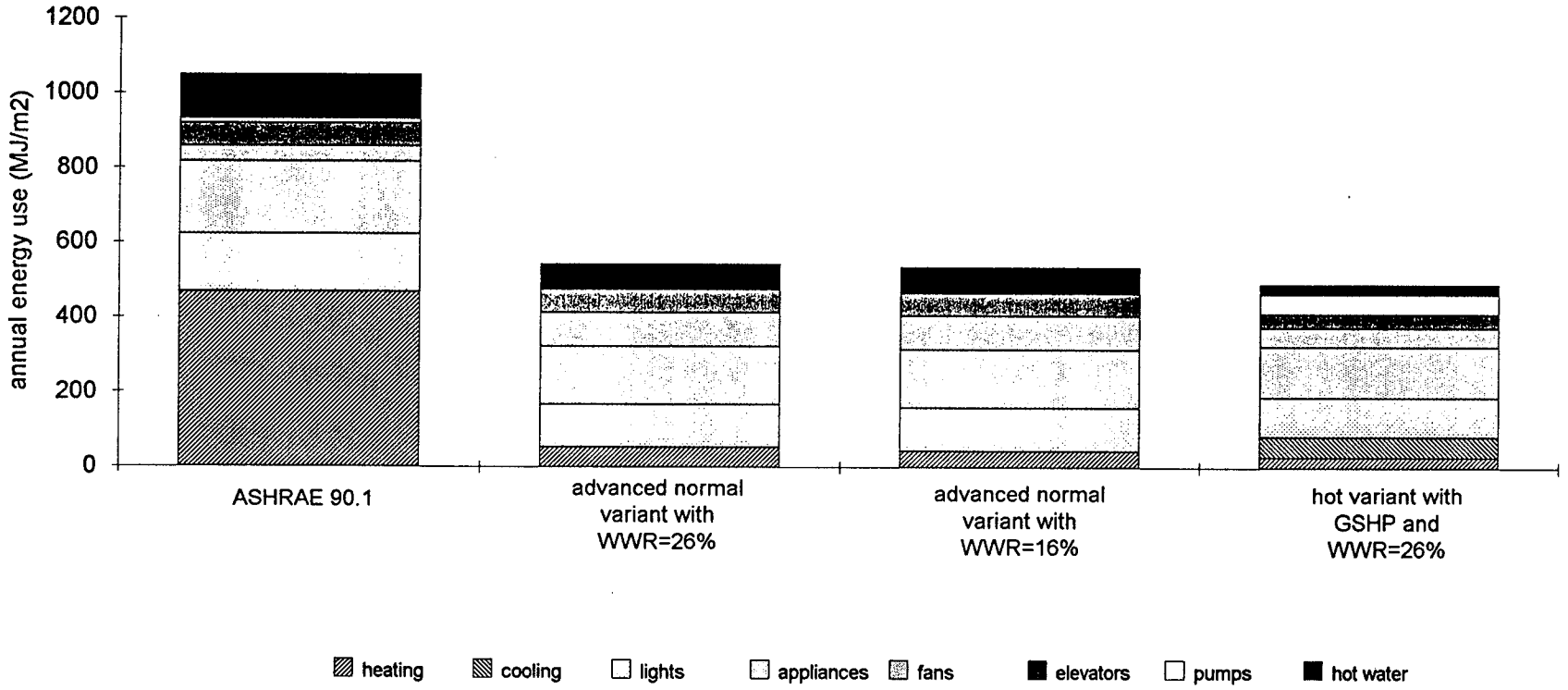
- a further 12% reduction in household appliance energy use
- the addition of insulated metal spacers on the windows
- a 40% reduction in power demand of the elevators
- the replacement of the hot water hydronic system with a ground-source heat pump system that satisfied 60% of the hot water load through desuperheating.

This simulation resulted in a 30% savings versus the advanced normal variant and a 75% savings versus the ASHRAE 90.1 base case.

The small MUR was modelled without mechanical cooling in the ASHRAE 90.1 and the advanced normal variant simulations, but with cooling in the hot variant. An innovative cooling simulation, however, was not performed.


Small Multi-Unit Residential Building in Montreal
Energy Cost
annual energy cost ($)
30000
25000
20000
15000
10000
5000
0
ASHRAE 90.1
advanced normal variant with WWR=26%
hot variant with GSHP and WWR=26%
electricity
gas

Small Multi-Unit Residential Building in Montreal
Source Energy



Source Energy is equal to the sum of purchased fuel energy and three times purchased electrical energy.

SMALL MULTI-UNIT RESIDENTIAL BUILDING IN MONTREAL

	ASHRAE 90.1	advanced normal variant with WWR=26%	advanced normal variant with WWR=16%	hot variant with GSHP & WWR=26%
lights	300 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit
	schedule G	schedule G	schedule G	schedule G
	8.6 W/m² in hallways	8.6 W/m² in hallways	8.6 W/m² in hallways	8.6 W/m² in hallways†
	schedule H	schedule H	schedule H	schedule H
appliances	SHG=244.1 W/unit + 0.625 of floor area LHG=0.2*SHG	80% of ASHRAE 90.1	80% of ASHRAE 90.1	70% of ASHRAE 90.1
	schedule I	schedule I	schedule I	schedule I
occupants	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W
	schedule J	schedule J	schedule J	schedule J
wall	2.71 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	5.18 RSI insl. btwn wood framing	8.80 RSI insl. btwn wood framing	8.80 RSI insl. btwn wood framing	8.80 RSI insl. btwn wood framing
glazing	0.339 RSI	0.734 RSI	0.734 RSI	0.839 RSI
	SC=0.65 (N,E,S,W)	SC=0.70 (N,E,S,W)	SC=0.70 (N,E,S,W)	SC=0.70 (N,E,S,W)
	WWR=26%	WWR=26%	WWR=16%	WWR=26%
infiltration	0.19 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule H	schedule H	schedule H	schedule H
HVAC Base System	hydronic central heating	hydronic central heating	hydronic central heating	ground source heat pump EER=19.4 COP=3.74
Cooling	none	none	none	
Heating	gas fired boiler with 80% combustion efficiency	gas fired boiler with 95% efficiency, HRV 80% effective	gas fired boiler with 95% efficiency, HRV 80% effective	HRV 80% effective
	schedule H	schedule H	schedule H	schedule H
elevators				60% of base case
hot water	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	60% by ground source system desuperheating remainder by gas-fired storage heater 95% thermal efficiency
	996.48 W/unit	697.5 W/unit	697.5 W/unit	697.5 W/unit
	schedule K	schedule K	schedule K	schedule K

†motion detectors in hallways and stairwells

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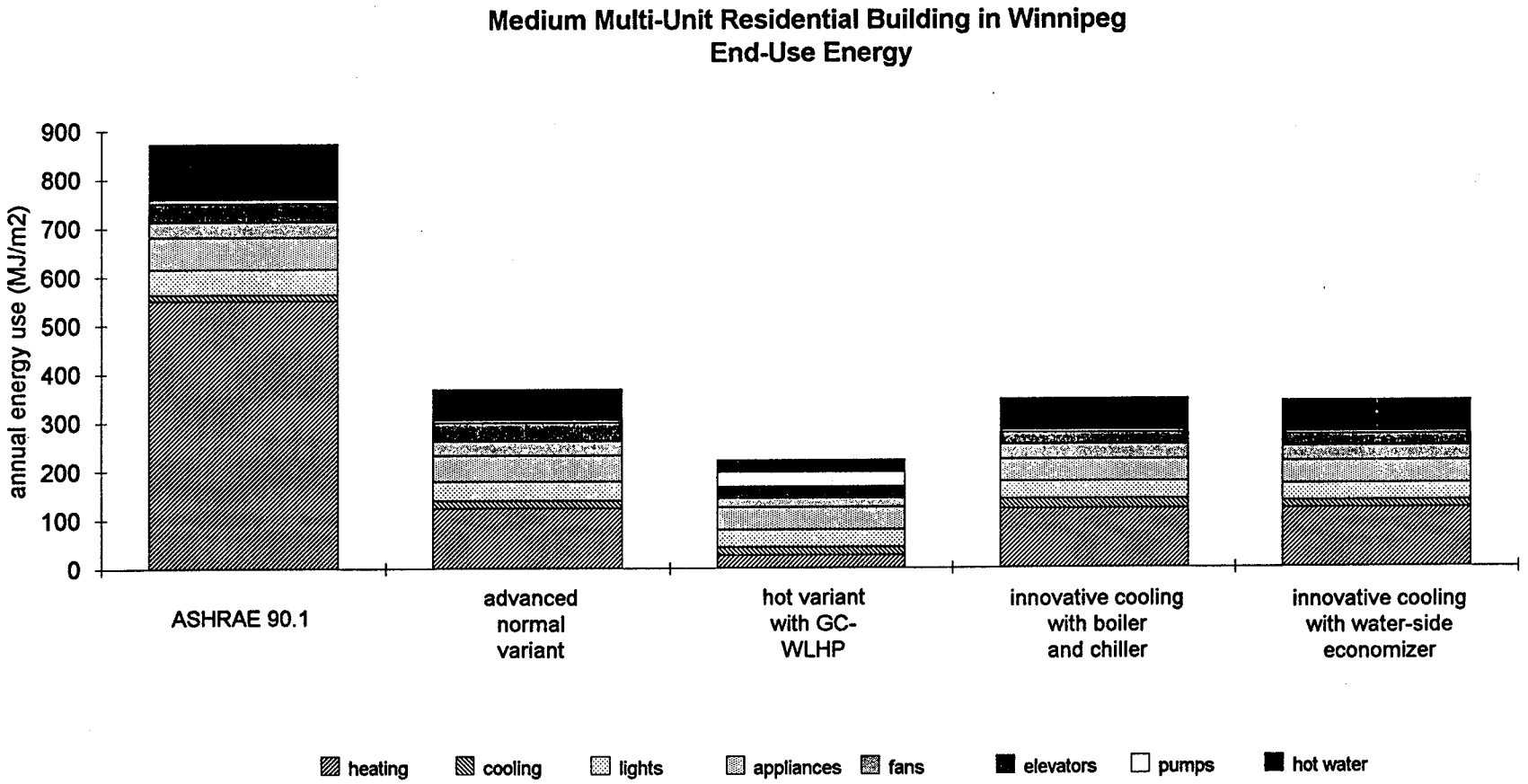

Medium Multi-Unit Residential Building in Winnipeg
End-Use Energy
annual energy use (MJ/m2)
900
800
700
600
500
400
300
200
100
0
ASHRAE 90.1
advanced normal variant
hot variant with GC-WLHP
innovative cooling with boiler and chiller
innovative cooling with water-side economizer
heating
cooling
lights
appliances
fans
elevators
pumps
hot water

MEDIUM MULTI-UNIT RESIDENTIAL BUILDING IN WINNIPEG

Five simulations were performed on the medium multi-unit residential building. The ASHRAE 90.1 simulation resulted in an annual energy use of 873 MJ/m^2.

One simulation was performed at the advanced normal variant level. Changes from the ASHRAE 90.1 run included:

- lighting power reduced by 25%
- a 20% reduction in household appliance energy use
- wall and roof insulating values improved by 80% and 170%, respectively
- infiltration reduced by almost 50%
- a 19% increase in gas-fired boiler efficiency
- a 15% increase in chiller efficiency
- the addition of individual suite heat recovery ventilators with 80% effectiveness
- a 30% reduction in hot water load
- a 23% increase in gas-fired DHW boiler efficiency
- a small reduction in window area
- an improvement in windows to foam-vinyl, bronze coated, argon filled, triple glazing (low-e coating on inside) with metal spacers from vinyl, bronze coated, double glazing with metal spacers.

The advanced normal variant simulation resulted in 58% savings in end-use energy.

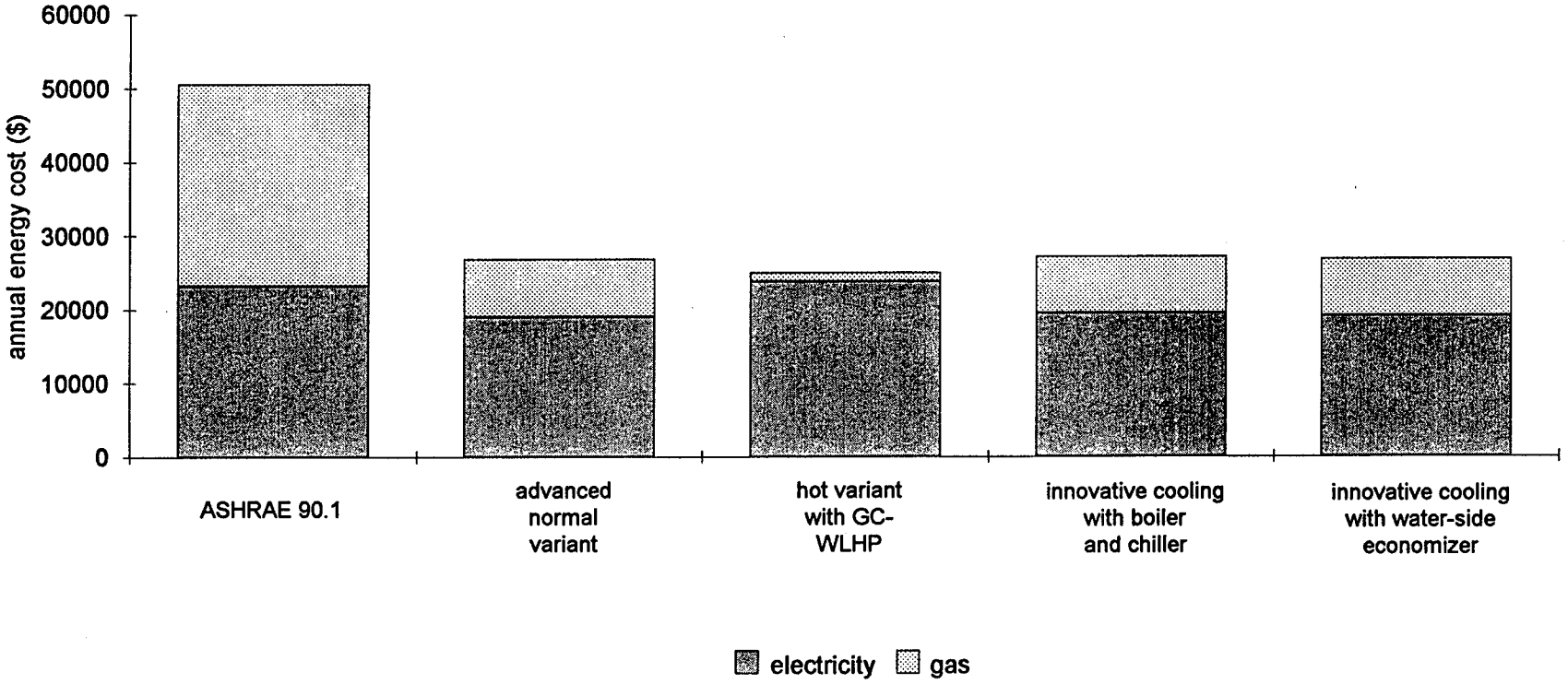
One simulation was performed at the hot variant level. Changes relative to the advanced normal variant included:

- a further 12% reduction in household appliance energy use
- the addition of insulated metal spacers on the windows
- a 40% reduction in power demand of the elevators
- the replacement of the two-pipe fan coil system with chiller and boiler with a ground-source heat pump system that satisfied 60% of the hot water load through desuperheating.

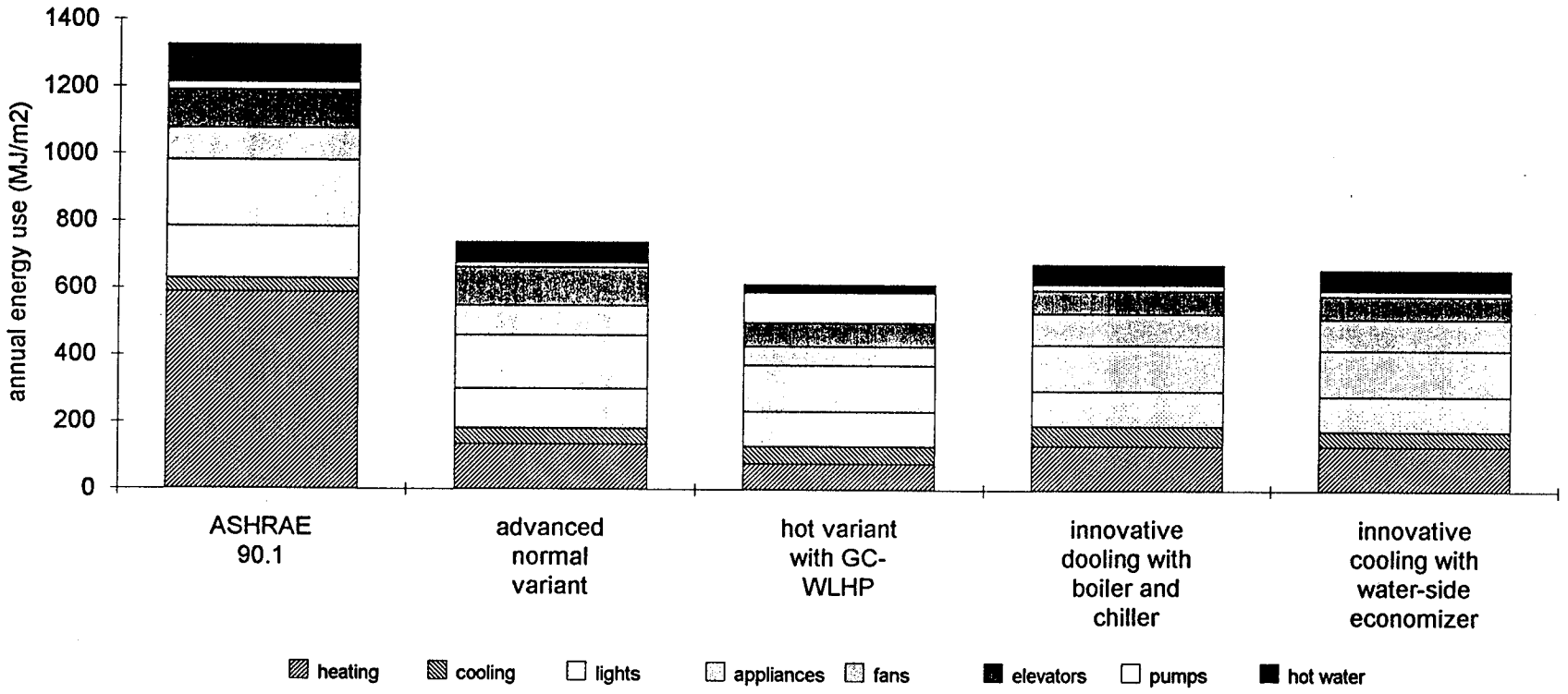
The hot variant simulation showed a 40% reduction in energy from the advanced normal simulation and a 75% reduction versus the ASHRAE 90.1 base case.

Two simulations were performed at the innovative cooling level. The ground-source heat pump system of the hot variant was replaced with a four-pipe fan coil, similar to the two-pipe system of the advanced normal variant. The first simulation provided a reference for the addition of a strainer cycle in the other. A 25% reduction in space cooling energy was achieved.

Medium Multi-Unit Residential Building in Winnipeg
Energy Cost



Medium Multi-Unit Residential Building in Winnipeg
Source Energy



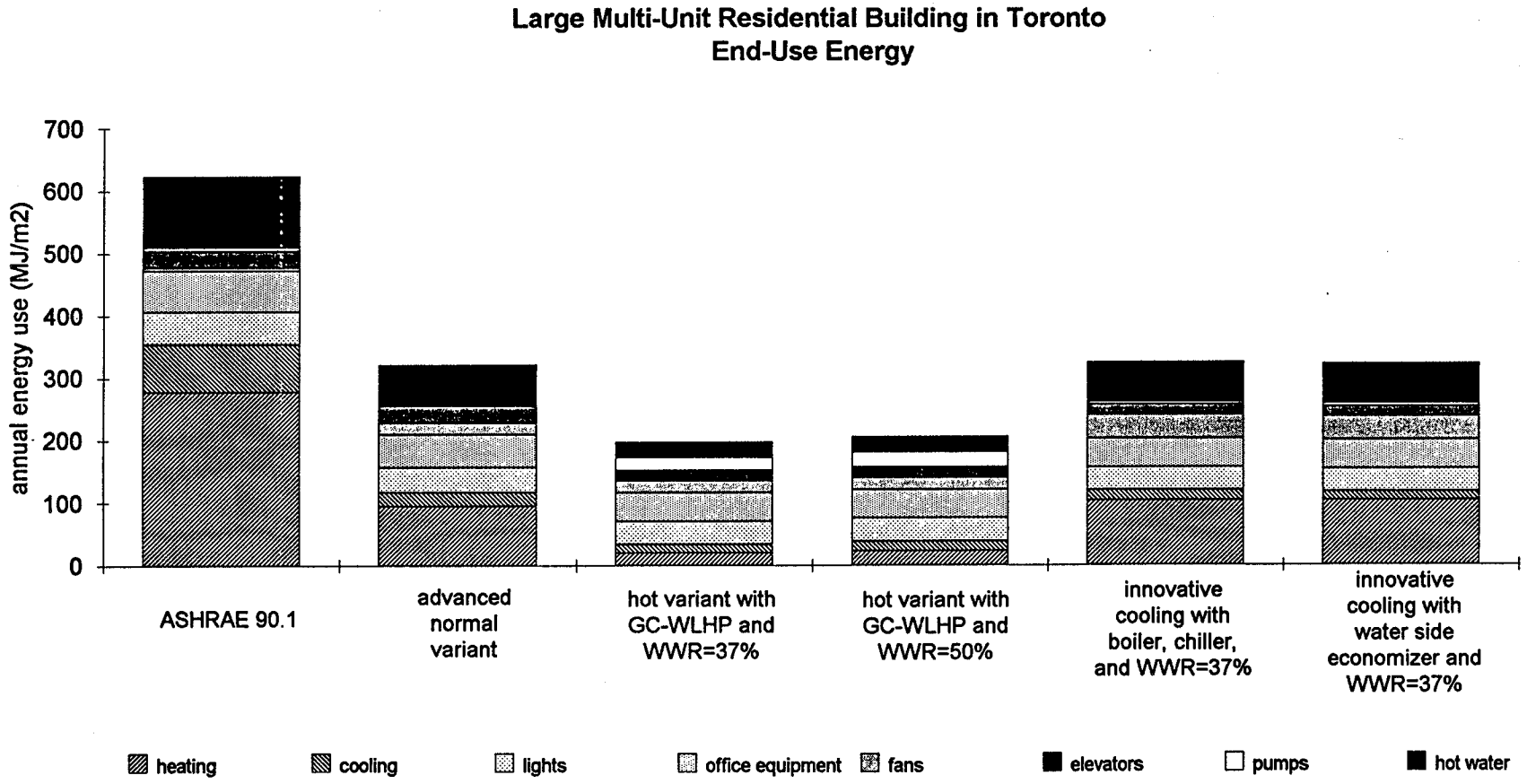
Source Energy is equal to the sum of purchased fuel energy and three times purchased electrical energy.

MEDIUM MULTI-UNIT RESIDENTIAL BUILDING IN WINNIPEG

	ASHRAE 90.1	advanced normal variant with WWR=28%	hot variant with GC-WLHP	innovative cooling boiler, chiller	innovative cooling waterside economizer
lights	300 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit
	schedule G	schedule G	schedule G	schedule G	schedule G
	8.6 W/m² in hallways	8.6 W/m² in hallways	8.6 W/m² in hallways†	8.6 W/m² in hallways†	8.6 W/m² in hallways†
	schedule H	schedule H	schedule H	schedule H	schedule H
appliances	SHG=244.1 W/unit + 0.625 of floor area LHG=0.2*SHG	80% of ASHRAE 90.1	70% of ASHRAE 90.1	70% of ASHRAE 90.1	70% of ASHRAE 90.1
	schedule I	schedule I	schedule I	schedule I	schedule I
occupants	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W
	schedule J	schedule J	schedule J	schedule J	schedule J
wall	3.91 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	2.71 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing
glazing	0.339 RSI	0.734 RSI	0.839 RSI	0.839 RSI	0.839 RSI
	SC=0.65 (N,E,S,W)	SC=0.45 (N,E,S,W)	SC=0.45 (N,E,S,W)	SC=0.45 (N,E,S,W)	SC=0.45 (N,E,S,W)
	WWR=29%	WWR=28%	WWR=28%	WWR=28%	WWR=28%
infiltration	0.19 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule H	schedule H	schedule H	schedule H	schedule H
HVAC Base System	hydronic central heating/cooling 2 pipe system	hydronic central heating/cooling 2 pipe system	ground coupled water loop heat pump EER=19.4 COP=3.53	hydronic central heating / cooling 4 pipe system	hydronic central heating / cooling 4 pipe system
Cooling	chiller EER=13.0	chiller EER=15.0		chiller EER=15.0	water side economizer, chiller EER=15.0
Heating	gas fired boiler with 80% combustion efficiency	gas fired boiler with 95% efficiency, HRV 80% effective	HRV 80% effective	gas fired boiler with 95% efficiency, HRV 80% effective	gas fired boiler with 95% efficiency, HRV 80% effective
	schedule H	schedule H	schedule H	schedule H	schedule H
elevators			60% of base case	60% of base case	60% of base case
hot water	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 95% thermal efficiency	60% by ground source system-desuperheating remainder by gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency
	996.48 W/unit	697.5 W/unit	697.5 W/unit	697.5 W/unit	697.5 W/unit
	schedule K	schedule K	schedule K	schedule K	schedule K

†motion detectors in hallways and stairwells

medmurb.wpd


Large Multi-Unit Residential Building in Toronto
End-Use Energy
annual energy use (MJ/m2)
700
600
500
400
300
200
100
0
ASHRAE 90.1
advanced normal variant
hot variant with GC-WLHP and WWR=37%
hot variant with GC-WLHP and WWR=50%
innovative cooling with boiler, chiller, and WWR=37%
innovative cooling with water side economizer and WWR=37%
heating
cooling
lights
office equipment
fans
elevators
pumps
hot water

LARGE MULTI-UNIT RESIDENTIAL BUILDING IN TORONTO

Six simulations were performed on the large multi-unit residential building. The ASHRAE 90.1 simulation resulted in an annual energy use of 625 MJ/m^2.

One simulation was performed at the advanced normal variant level. Changes from the ASHRAE 90.1 run included:

- lighting power reduced by 25%
- a 20% reduction in household appliance energy use
- wall and roof insulating values improved by 190% and 170%, respectively
- infiltration reduced by almost 50%
- an 18% and 47% increase in heat pump heating and cooling efficiency
- a 19% increase in gas-fired boiler efficiency
- the addition of heat recovery ventilators at 80% effectiveness to the suites
- a 30% reduction in hot water load
- a 23% increase in gas-fired DHW boiler efficiency
- a 28% increase in window area
- an improvement in windows to foam-vinyl, bronze coated, argon filled, triple glazing (low-e coating on inside) with metal spacers from vinyl, bronze coated, double glazing with metal spacers.

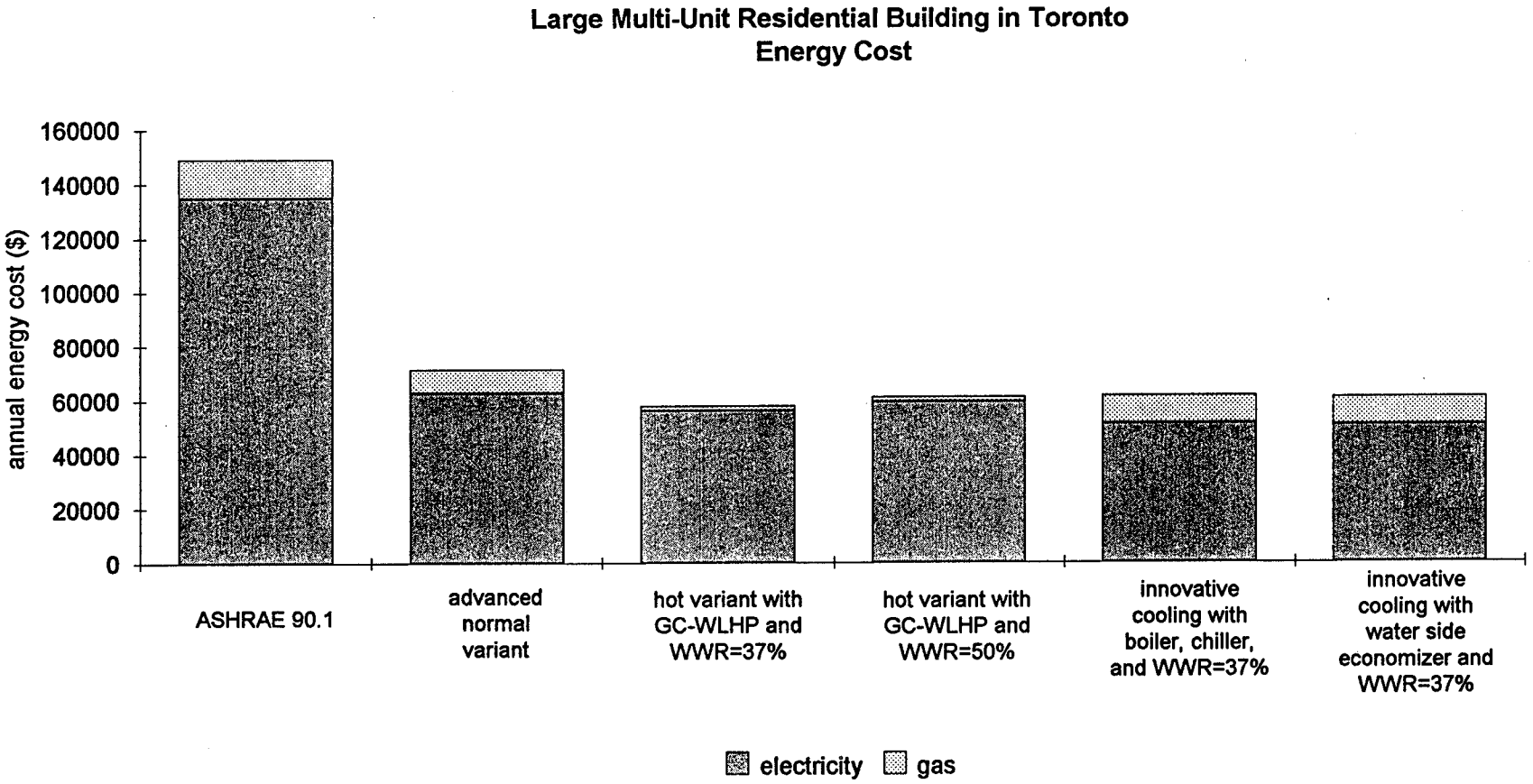
This simulation showed almost a 50% reduction in energy versus the ASHRAE 90.1 base case.

Two simulations were performed at the hot variant level, one with a window to wall ratio of 37%, the other with a ratio of 50%. Changes relative to the advanced normal variant included:

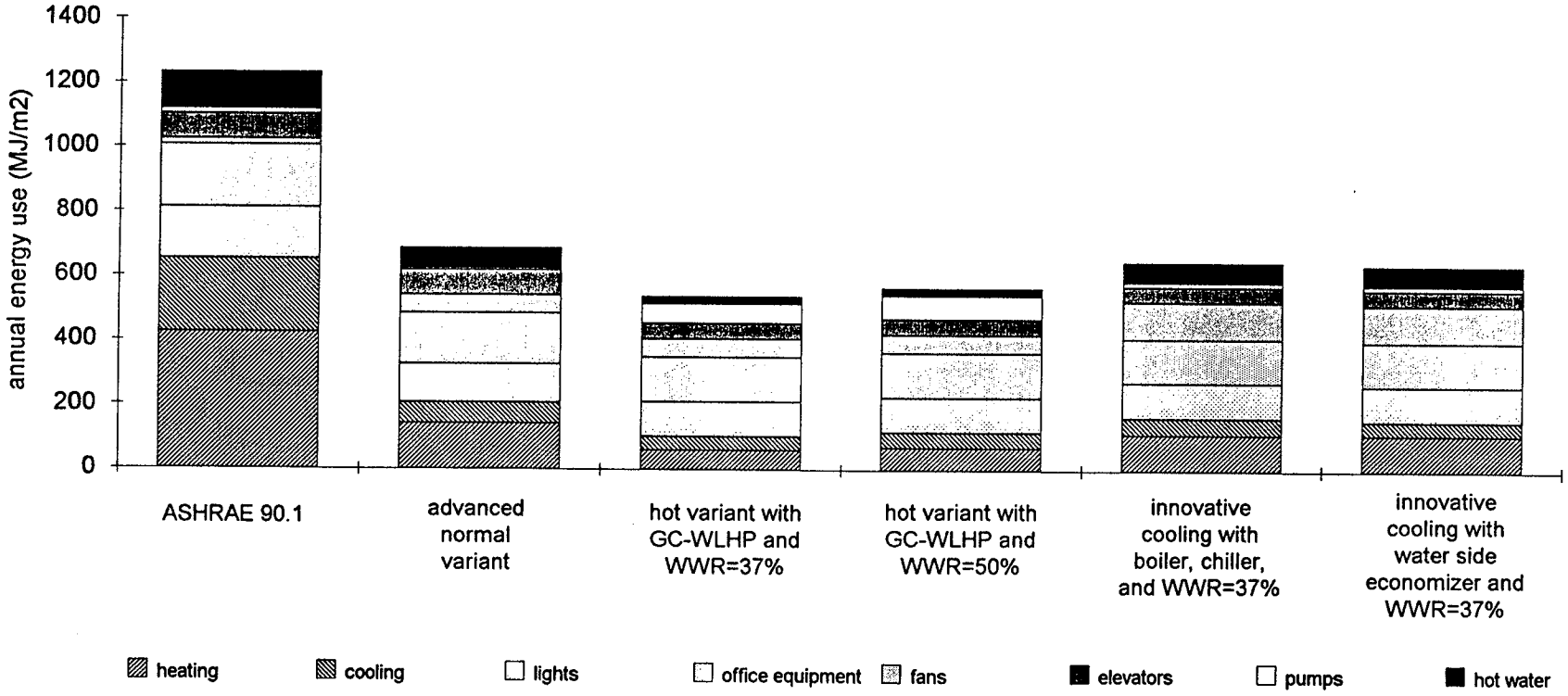
- a further 12% reduction in household appliance energy use
- the addition of insulated metal spacers on the windows
- a 40% reduction in power demand of the elevators
- the replacement of the chiller and boiler with a ground-source heat exchanger. Again, 60% of the hot water load was satisfied through desuperheating.

The simulation with the lower window to wall ratio showed a 68% lower building energy use than the ASHRAE 90.1 base case.

Two simulations were performed at the innovative cooling level. The ground-source heat pump system of the hot variant was replaced with a four-pipe fan coil system. The first simulation provided a reference for the addition of a strainer cycle in the other. A 15% reduction in space cooling energy, less than 1% of the building total, was achieved.


Large Multi-Unit Residential Building in Toronto
Energy Cost
annual energy cost ($)
160000
140000
120000
100000
80000
60000
40000
20000
0
ASHRAE 90.1
advanced normal variant
hot variant with GC-WLHP and WWR=37%
hot variant with GC-WLHP and WWR=50%
innovative cooling with boiler, chiller, and WWR=37%
innovative cooling with water side economizer and WWR=37%
electricity
gas

Large Multi-Unit Residential Building in Toronto
Source Energy



Source Energy is equal to the sum of purchased fuel energy and three times purchased electrical energy.

LARGE MULTI-UNIT RESIDENTIAL BUILDING IN TORONTO

	ASHRAE 90.1	advanced normal variant	hot variant with GC-WLHP & WWR=37%	hot variant with GC-WLHP & WWR=50%	innovative cooling boiler, chiller & WWR=37%	innovative cooling, waterside economizer & WWR=37%
lights	300 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit	225 W/dwelling unit
	schedule G	schedule G	schedule G	schedule G	schedule G	schedule G
	8.6 W/m² in hallways	8.6 W/m² in hallways	8.6 W/m² in hallways†	8.6 W/m² in hallways†	8.6 W/m² in hallways†	8.6 W/m² in hallways†
	schedule H	schedule H	schedule H	schedule H	schedule H	schedule H
appliances	SHG=244.1 W/unit + 0.625 of floor area LHG=0.2*SHG	80% of ASHRAE 90.1	70% of ASHRAE 90.1	70% of ASHRAE 90.1	70% of ASHRAE 90.1	70% of ASHRAE 90.1
	schedule I	schedule I	schedule I	schedule I	schedule I	schedule I
occupants	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W	2 pers./unit SHG=6.74 W LHG=55.7 W
	schedule J	schedule J	schedule J	schedule J	schedule J	schedule J
wall	2.45 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI	7.04 RSI
roof	2.71 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing	7.34 RSI insl. btwn metal framing
glazing	0.339 RSI	0.734 RSI	0.839 RSI	0.839 RSI	0.839 RSI	0.839 RSI
	SC=O.65 (N,E,S,W)	SC=0.20 (N,E,S,W)	SC=0.20 (N,E,S,W)	SC=0.20 (N,E,S,W)	SC=0.20 (N,E,S,W)	SC=0.20 (N,E,S,W)
	WWR=29%	WWR=37%	WWR=37%	WWR=50%	WWR=37%	WWR=37%
infiltration	0.19 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²	0.10 L/sm²
	schedule H	schedule H	schedule H	schedule H	schedule H	schedule H
HVAC Base System	water source heat pump with COP=3.8 EER=10.2	water source heat pump with COP=4.5 EER=15.0	ground coupled water loop heat pump EER=19.4 COP=3.82	ground coupled water loop heat pump EER=19.4 COP=3.82	hydronic central heating / cooling 4 pipe system	hydronic central heating / cooling 4 pipe system
Cooling	cooling tower	cooling tower			chiller EER=15.0	water side econo., chiller EER=15.0
Heating	gas fired boiler with 80% combustion efficiency	gas fired boiler with 95% efficiency, HRV 80% effective	HRV 80% effective	HRV 80% effective	gas fired boiler with 95% efficiency, HRV 80% effective	gas fired boiler with 95% efficiency, HRV 80% effective
	schedule H	schedule H	schedule H	schedule H	schedule H	schedule H
elevators			60% of base case	60% of base case	60% of base case	60% of base case
hot water	gas-fired storage heater 77% thermal efficiency	gas-fired storage heater 95% thermal efficiency	60% by ground source system-desuperheating remainder by gas-fired storage heater 95% thermal efficiency	60% by ground source system-desuperheating remainder by gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency	gas-fired storage heater 95% thermal efficiency
	996.48 W/unit	697.5 W/unit	697.5 W/unit	697.5 W/unit	697.5 W/unit	697.5 W/unit
	schedule K	schedule K	schedule K	schedule K	schedule K	schedule K

†motion detectors in hallways and stairwells

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APPENDIX

Tabulated Energy End-Use and Source Energy End-Use Data

Referenced Schedules

SOURCE ENERGY END-USE DATA*

(MJ/m2)

Small Office	ASHRAE 90.1	advanced normal variant wwr=26%	advanced normal variant wwr=33%	hot variant with GSHP wwr=33%	hot variant with GSHP wwr=50%	innovative cooling: desic/evap cooling, wwr=33%	hot variant: 100% OA, GSHP, heat recovery, wwr=33%
heating	250	95	113	72	81	200	78
cooling	120	72	78	39	48	10	42
lights	567	330	330	144	138	144	144
office equipment	246	246	246	135	135	135	135
fans	174	99	108	15	15	36	30
elevators	99	99	99	60	60	60	60
pumps	12	6	6	57	57	3	63
hot water	14	14	14	0	0	14	0
total	1482	961	994	522	534	602	552

Medium Office	ASHRAE 90.1	advanced normal variant wwr=25%	advanced normal variant wwr=36%	advanced normal variant wwr=50%	hot variant: GC-WLHP, wwr=36%	hot variant: GC-WLHP, wwr=50%	hot variant: boiler, chiller wwr=36%	hot variant: boiler, chiller wwr=50%	innovative cooing: water side econo. wwr=36%	innovative cooing: water side econo. wwr=50%	hot variant: GC-WLHP, 100% OA heat recovery wwr=36%	hot variant: GC-WLHP, 100% OA heat recovery wwr=50%
heating	323.7	138.62	167.03	207.5	106.71	115.05	193.81	218.59	193.85	218.59	185.19	188.97
cooling	171	114.78	129	149.1	56.22	66.9	77.64	94.8	52.98	64.8	43.65	53.46
lights	516.3	328.8	328.8	328.8	152.25	147.6	152.1	147.57	152.25	147.6	152.25	147.57
office equipment	246.6	246.6	246.6	246.6	136.2	136.2	136.35	136.35	136.35	136.35	136.35	136.35
fans	104.4	68.7	80.4	96	14.61	14.61	55.71	69.9	55.71	69.9	60.12	60.12
elevators	78.3	78.3	78.3	78.3	47.01	47.01	47.01	47.01	47.01	47.01	47.01	47.01
pumps	39.3	26.4	29.88	34.71	99.6	100.35	21.99	25.89	21.96	25.89	104.94	105.93
hot water	15.3	15.33	15.3	15.3	0	0	12.49	12.49	12.49	12.49	0	0
total	1494.9	1017.53	1075.31	1156.31	612.6	627.72	697.1	752.6	672.6	722.63	729.51	739.41

Large Office	ASHRAE 90.1	advanced normal variant wwr=25%	advanced normal variant wwr=36%	hot variant: wwr=36%	hot variant: wwr=50%	innovative cooling: water side econo. wwr=36%	hot variant: 100% OA heat recovery wwr=36%
heating	257	61	80	106	124	106	95
cooling	132	81	84	54	60	45	42
lights	516	330	330	153	147	153	153
office equipment	246	246	246	135	135	135	135
fans	93	51	54	39	48	39	42
elevators	66	66	66	39	39	39	39
pumps	30	18	18	15	18	15	12
hot water	15	15	15	13	13	13	13
total	1355	868	893	554	584	545	531

Small MUR	ASHRAE 90.1	advanced normal variant wwr=26%	advanced normal variant wwr=16%	hot variant: GSHP wwr=26%
heating	468.4	52.8	44.24	27.87
cooling	0	0	0	56.25
lights	153	114.9	114.9	103.65
appliances	194.1	155.4	155.4	135.84
fans	42.3	89.88	89.88	51.27
elevators	61.2	61.2	61.14	36.69
pumps	10.56	1.38	1.17	52.2
hot water	120.9	68.6	68.6	27.43
total	1050.46	544.16	535.33	491.2

Medium MUR	ASHRAE 90.1	advanced normal variant	hot variant: GC-WLHP	hot variant: boiler and chiller	innovative cooling: water side econo.
heating	588	135	78	133	133
cooling	39	48	51	60	45
lights	156	117	105	105	105
appliances	198	159	138	138	138
fans	96	90	57	93	93
elevators	114	114	69	69	69
pumps	21	12	90	15	15
hot water	115	65	26	65	65
total	1327	740	614	678	663

Large MUR	ASHRAE 90.1	advanced normal variant	hot variant: GC-WLHP wwr=37%	hot variant: GC-WLHP wwr=50%	hot variant: boiler, chiller wwr=37%	innovative cooling: water side econo. wwr=37%
heating	424	141	60	69	113	113
cooling	228	66	42	48	51	42
lights	159	120	108	108	108	108
office equipment	195	156	138	138	138	138
fans	18	57	57	57	114	114
elevators	78	78	48	48	48	48
pumps	15	6	60	72	12	12
hot water	115	65	26	26	65	65
total	1232	689	539	566	649	640

*Source Energy as defined in the C-2000 criteria is equal to the sum of electrical energy multiplied by three and fuel energy.

ENERGY END-USE DATA

(MJ/m2)

Small Office	ASHRAE 90.1	advanced normal variant wwr=26%	advanced normal variant wwr=33%	hot variant with GSHP wwr=33%	hot variant with GSHP wwr=50%	innovative cooling: desic/evap cooling, wwr=33%	hot variant: 100% OA, GSHP, heat recovery, wwr=33%
heating	228	87	103	24	27	192	26
cooling	40	24	26	13	16	10	14
lights	189	110	110	48	46	48	48
office equipment	82	82	82	45	45	45	45
fans	58	33	36	5	5	12	10
elevators	33	33	33	20	20	20	20
pumps	4	2	2	19	19	1	21
hot water	14	14	14	0	0	14	0
total	648	385	406	174	178	342	184

Medium Office	ASHRAE 90.1	advanced normal variant wwr=25%	advanced normal variant wwr=36%	advanced normal variant wwr=50%	hot variant: GC-WLHP, wwr=36%	hot variant: GC-WLHP, wwr=50%	hot variant: boiler, chiller wwr=36%	hot variant: boiler, chiller wwr=50%	innovative cooing: water side econo. wwr=36%	innovative cooing: water side econo. wwr=50%	hot variant: GC-WLHP, 100% OA heat recovery wwr=36%	hot variant: GC-WLHP, 100% OA heat recovery wwr=50%
heating	297.9	125.94	151.61	188.3	35.57	38.35	177.07	199.53	177.11	199.53	61.73	62.99
cooling	57	38.26	43	49.7	18.74	22.3	25.88	31.6	17.66	21.6	14.55	17.82
lights	172.1	109.6	109.6	109.6	50.75	49.2	50.7	49.19	50.75	49.2	50.75	49.19
office equipment	82.2	82.2	82.2	82.2	45.4	45.4	45.45	45.45	45.45	45.45	45.45	45.45
fans	34.8	22.9	26.8	32	4.87	4.87	18.57	23.3	18.57	23.3	20.04	20.04
elevators	26.1	26.1	26.1	26.1	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67
pumps	13.1	8.8	9.96	11.57	33.2	33.45	7.33	8.63	7.32	8.63	34.98	35.31
hot water	15.3	15.33	15.3	15.3	0	0	12.49	12.49	12.49	12.49	0	0
total	698.5	429.13	464.57	514.77	204.2	209.24	353.16	385.86	345.02	375.87	243.17	246.47

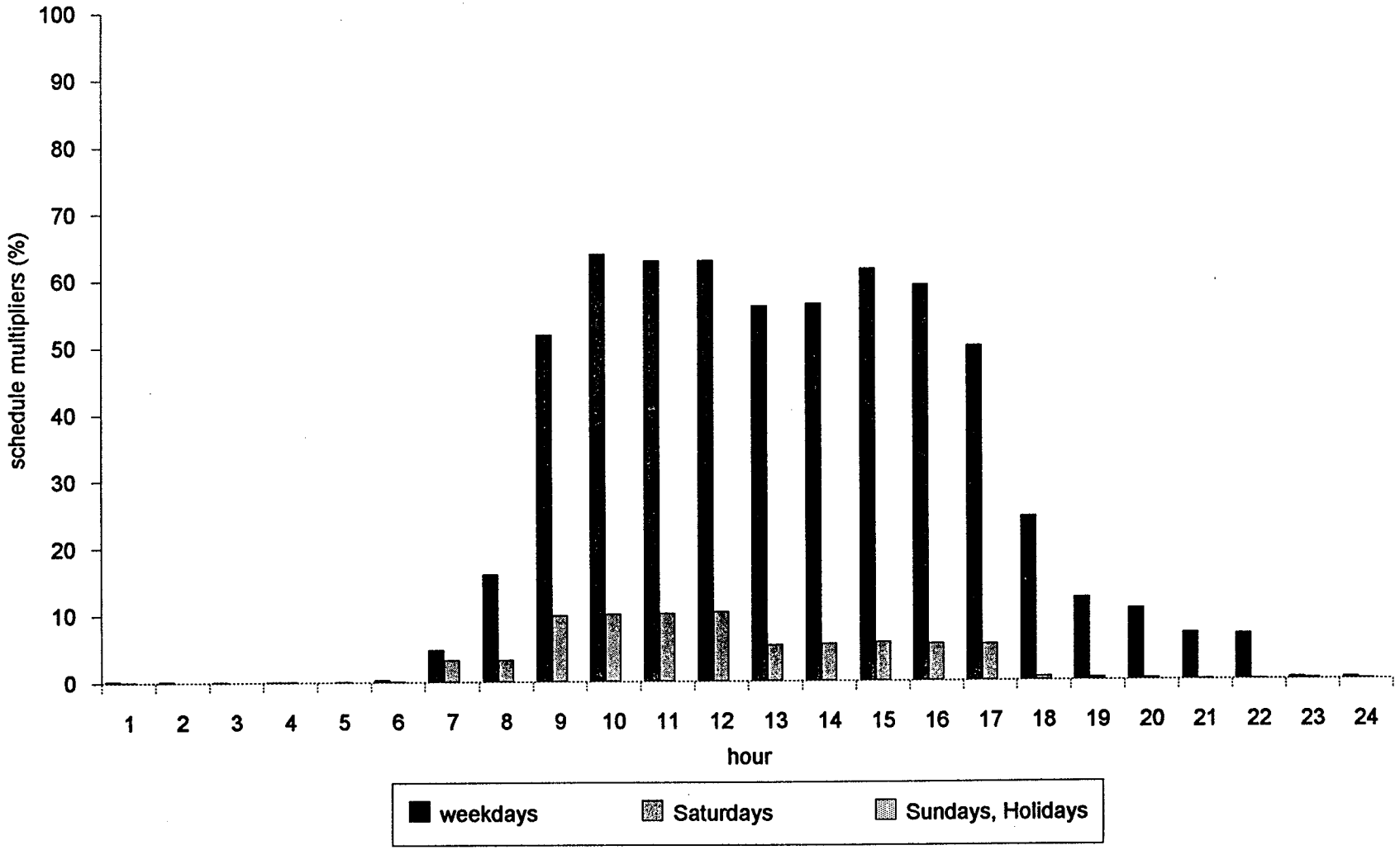
Large Office	ASHRAE 90.1	advanced normal variant wwr=25%	advanced normal variant wwr=36%	hot variant: wwr=36%	hot variant: wwr=50%	innovative cooling: water side econo. wwr=36%	hot variant: 100% OA heat recovery wwr=36%
heating	235	55	72	96	112	96	85
cooling	44	27	28	18	20	15	14
lights	172	110	110	51	49	51	51
office equipment	82	82	82	45	45	45	45
fans	31	17	18	13	16	13	14
elevators	22	22	22	13	13	13	13
pumps	10	6	6	5	6	5	4
hot water	15	15	15	13	13	13	13
total	611	334	353	254	274	251	239

Small MUR	ASHRAE 90.1	advanced normal variant wwr=26%	advanced normal variant wwr=16%	hot variant: GSHP wwr=26%
heating	439.2	48.82	40.92	9.29
cooling	0	0	0	18.75
lights	51	38.3	38.3	34.55
appliances	64.7	51.8	51.8	45.28
fans	14.1	29.96	29.96	17.09
elevators	20.4	20.4	20.38	12.23
pumps	3.52	0.46	0.39	17.4
hot water	120.9	68.6	68.6	27.43
total	713.82	258.34	250.35	182.02

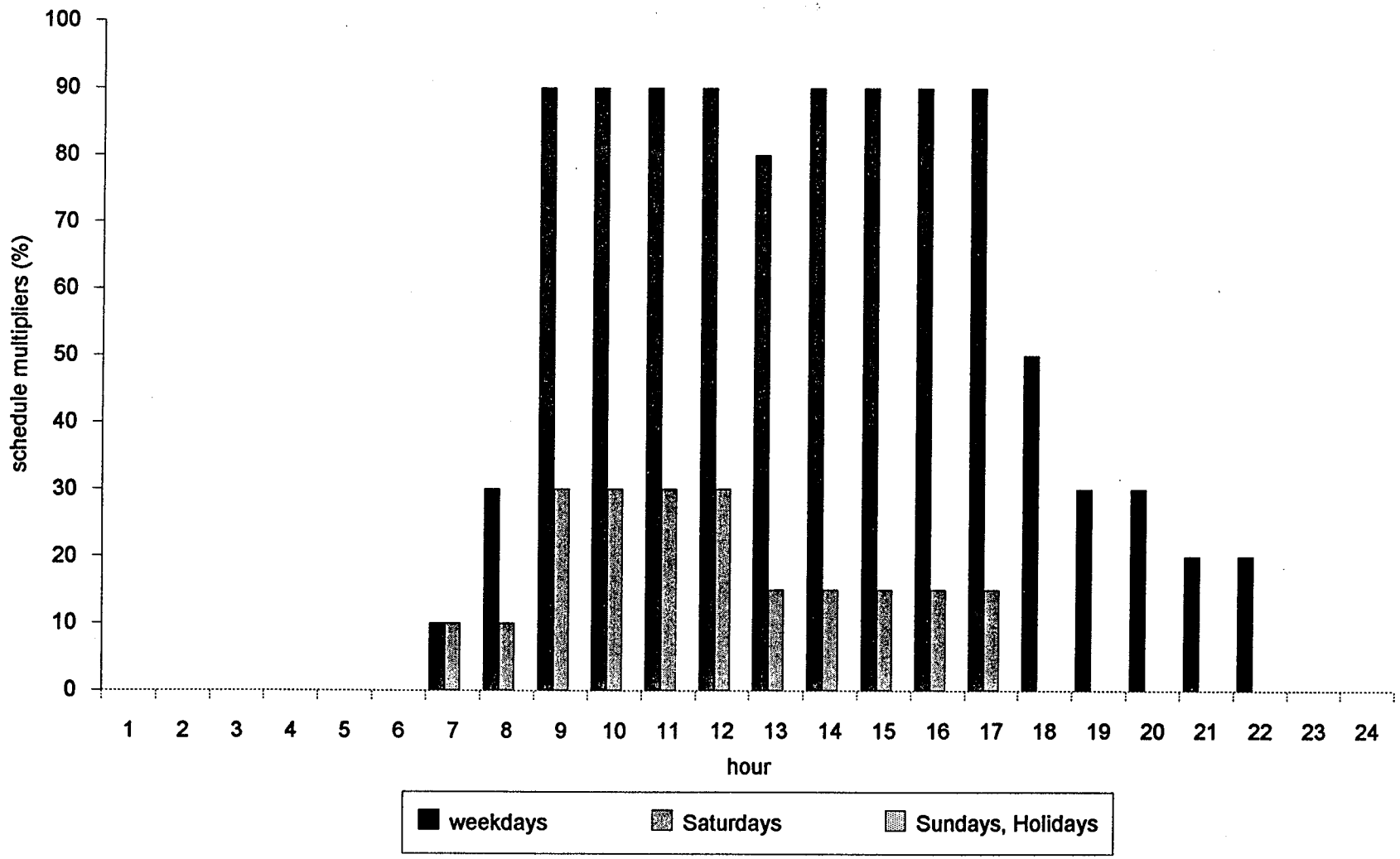
Medium MUR	ASHRAE 90.1	advanced normal variant	hot variant: GC-WLHP	hot variant: boiler and chiller	innovative cooling: water side econo.
heating	550	123	26	121	121
cooling	13	16	17	20	15
lights	52	39	35	35	35
appliances	66	53	46	46	46
fans	32	30	19	31	31
elevators	38	38	23	23	23
pumps	7	4	30	5	5
hot water	115	65	26	65	65
total	873	368	222	346	341

Large MUR	ASHRAE 90.1	advanced normal variant	hot variant: GC-WLHP wwr=37%	hot variant: GC-WLHP wwr=50%	hot variant: boiler, chiller wwr=37%	innovative cooling: water side econo. wwr=37%
heating	278	95	20	23	103	103
cooling	76	22	14	16	17	14
lights	53	40	36	36	36	36
office equipment	65	52	46	46	46	46
fans	6	19	19	19	38	38
elevators	26	26	16	16	16	16
pumps	5	2	20	24	4	4
hot water	115	65	26	26	65	65
total	624	321	197	206	325	322

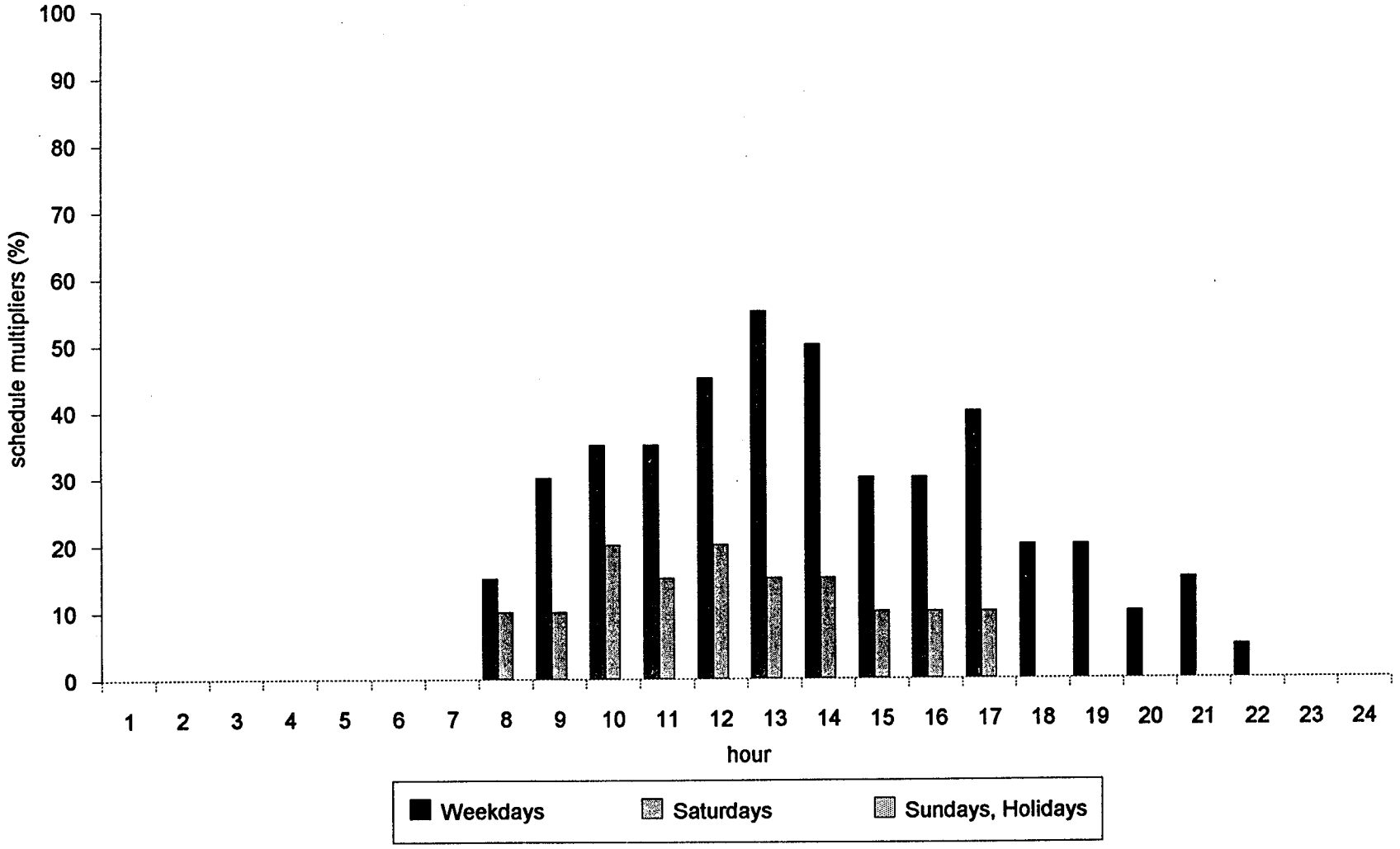
Schedule B - Office Lighting & Equipment with Smartbar Control



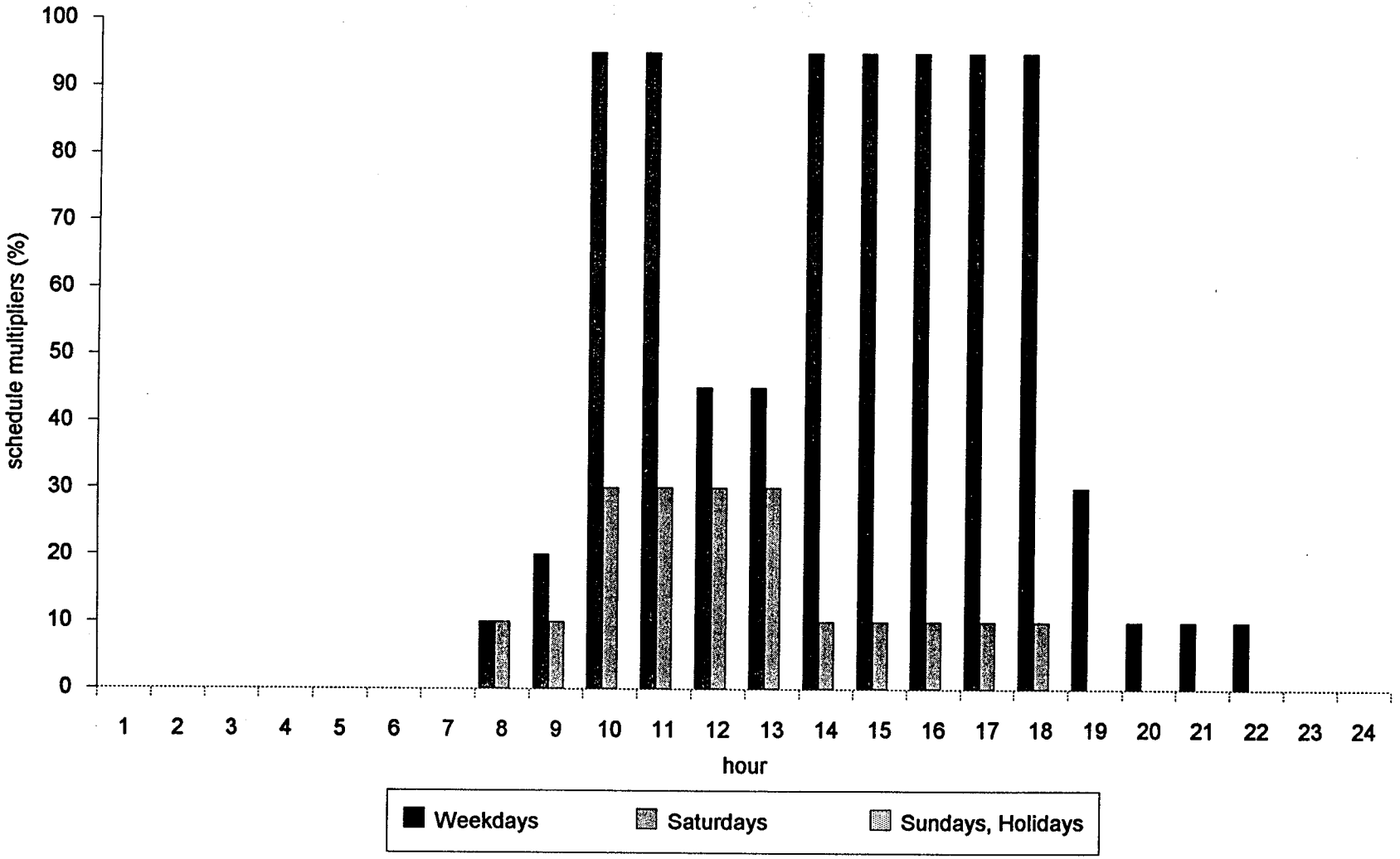
Schedule A - Office Lighting & Equipment



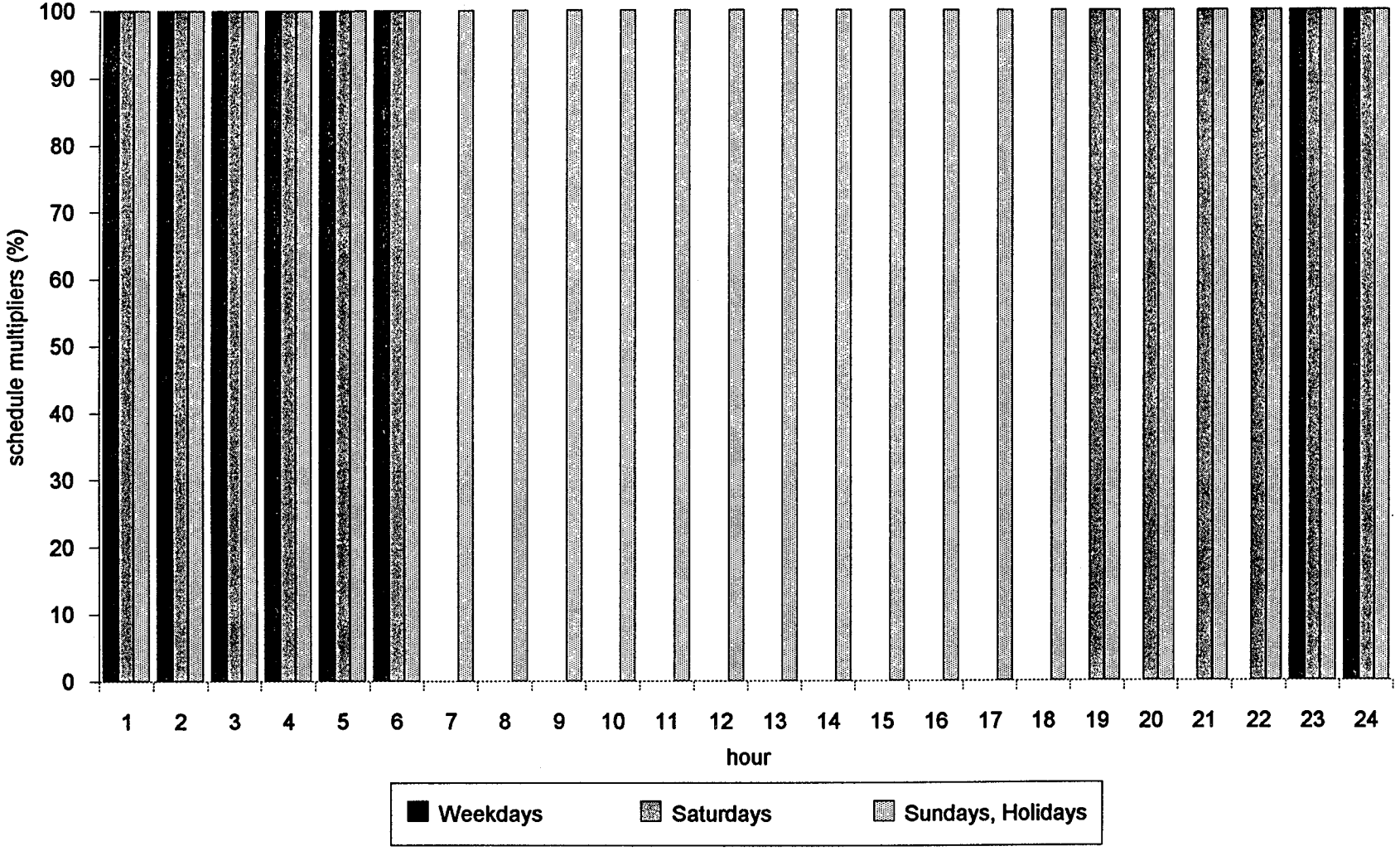
Schedule D - Office Service Hot Water



Schedule C - Office Occupancy



Schedule F - Office Infiltration

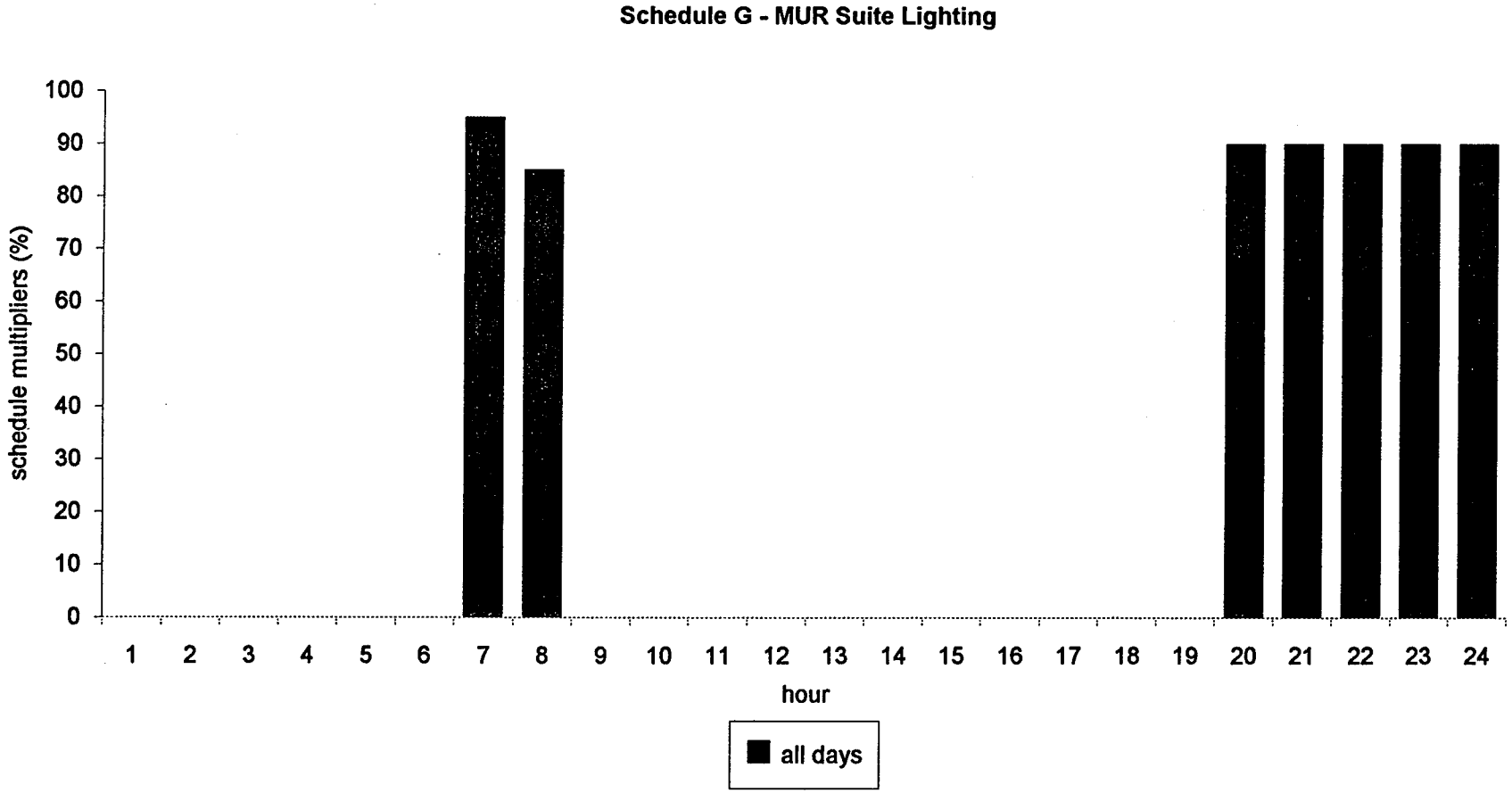


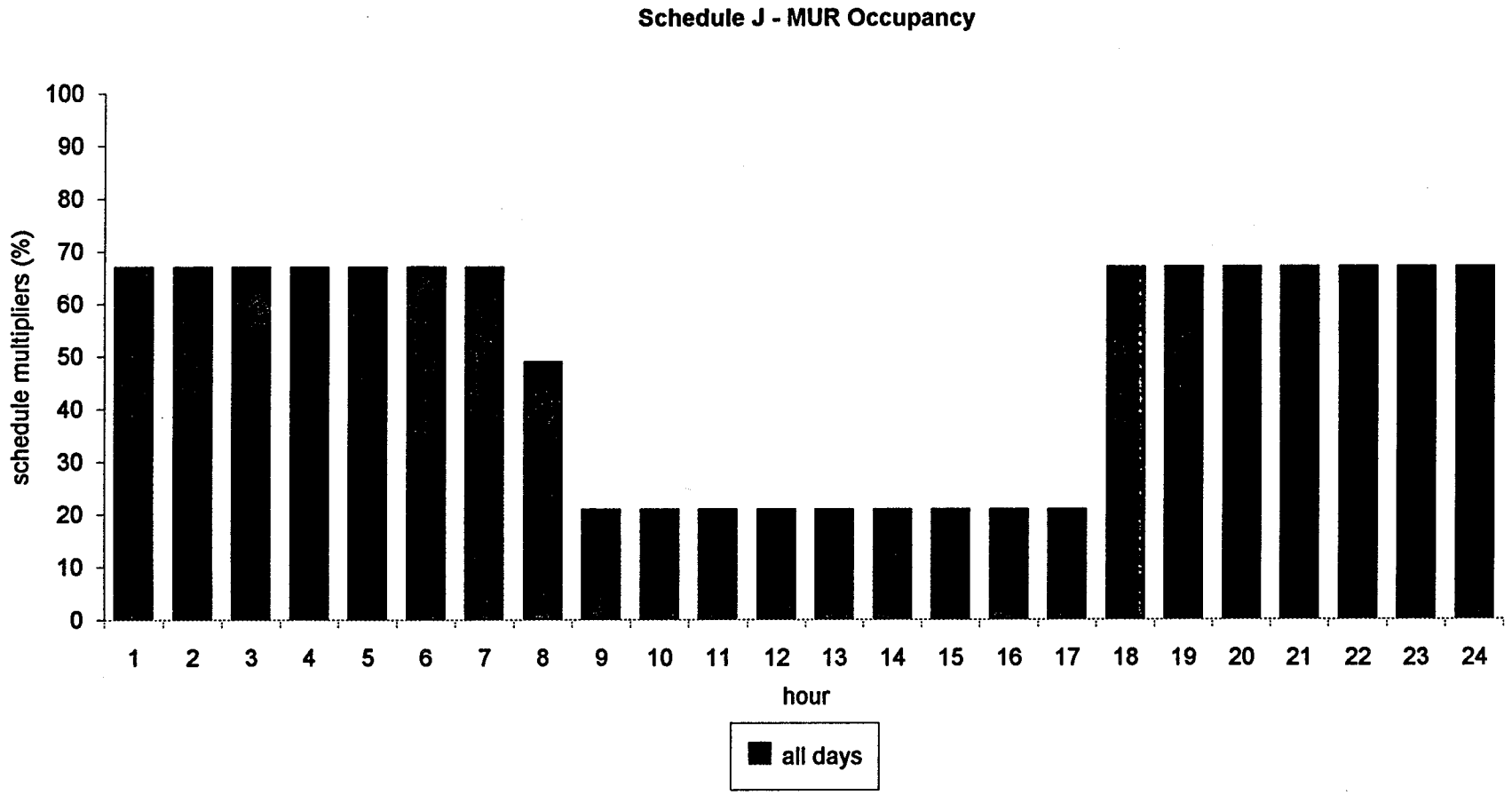
Schedule E - Office HVAC

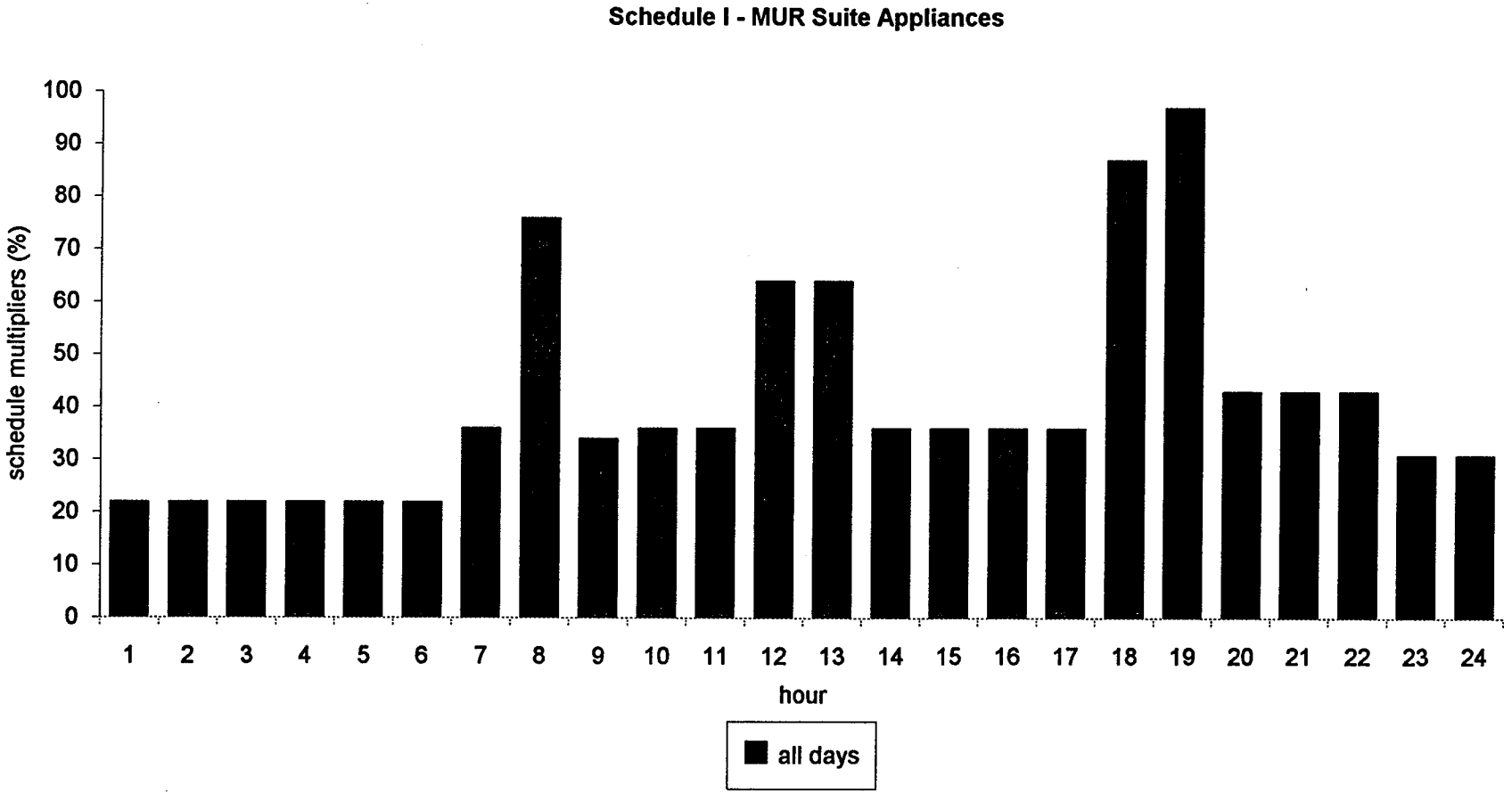
hour	Weekdays	Saturdays	Sundays, Holidays
1	off	off	off
2	off	off	off
3	off	off	off
4	off	off	off
5	off	off	off
6	off	off	off
7	on	on	off
8	on	on	off
9	on	on	off
10	on	on	off
11	on	on	off
12	on	on	off
13	on	on	off
14	on	on	off
15	on	on	off
16	on	on	off
17	on	on	off
18	on	on	off
19	on	off	off
20	on	off	off
21	on	off	off
22	on	off	off
23	off	off	off
24	off	off	off

Schedule H - MUR Hallway Lighting, Infiltration & HVAC

hour	Hallway Lighting All Days	Infiltration All Days	HVAC All Days
1	100	100	on
2	100	100	on
3	100	100	on
4	100	100	on
5	100	100	on
6	100	100	on
7	100	100	on
8	100	100	on
9	100	100	on
10	100	100	on
11	100	100	on
12	100	100	on
13	100	100	on
14	100	100	on
15	100	100	on
16	100	100	on
17	100	100	on
18	100	100	on
19	100	100	on
20	100	100	on
21	100	100	on
22	100	100	on
23	100	100	on
24	100	100	on


Schedule G - MUR Suite Lighting
schedule multipliers (%)
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
all days


Schedule J - MUR Occupancy
schedule multipliers (%)
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
all days


Schedule I - MUR Suite Appliances
schedule multipliers (%)
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
all days

Schedule K - MUR Service Hot Water