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A Staged Analysis of Building Code Impacts on Representative Buildings in Alaska

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ABSTRACT

Energy inefficient buildings located in cold climates require up to five times more energy to heat than more energy efficient buildings. More stringent construction codes will reduce building energy consumption and thereby lead to reduced energy costs and emissions. For this study, professional energy audits were conducted on two representative buildings and AkWarm Energy Modeling software models of the buildings were generated. The actual energy consumption of the buildings is compared to the modeled energy consumption. The representative buildings are then modeled as if they were constructed to 1975 and 2001 codes, and the energy consumption for the buildings under those construction codes is estimated. The study is novel because it uses actual energy consumption of the buildings to ground truth the models, and then considers how much energy those buildings would consume if their building envelopes were constructed to the standards of other eras. The two modeled buildings are similar to many other buildings located in cold climate regions such as Interior Alaska. Improving the energy efficiency of the existing building stock will reduce the energy consumption, energy costs, and the carbon footprint of the buildings. The findings show the predicted versus actual energy consumption for the two buildings as they are built. The findings also show that a more stringent construction code significantly reduces the energy consumption of the two buildings.

INTRODUCTION

Energy inefficient buildings located in cold climates have higher thermal loads than identical buildings located in more temperate climates due to the larger delta between the outdoor temperature and the desired indoor temperature. In fact, energy inefficient buildings located in cold regions require up to five times more energy to heat than more energy efficient buildings (Cold Climate Housing Research Center, 2019). Interior Alaska is classified as a Climate Zone 8, which is the coldest zone in the standards set forth by the International Energy Conservation Code (IECC) (IECC, 2021). The region averages more than 13,000 heating degree days per year (HDD65).

Commercial buildings in Alaska use an estimated 65 billion Btus of energy annually (Alaska Energy Authority, 2019). Due to the region's cold climate, space heating accounts for a large portion of total building energy use. An analysis of over 300 investment-grade energy audits performed on public buildings in Alaska found that, on average, space heating accounts for more than 70% of the total energy used in commercial buildings (Alaska Housing Finance Corporation, 2012).

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Many of the commercial buildings in Alaska are under insulated and over ventilated and were built to standards more appropriate for warmer climates. Alaska does not have a mandatory statewide building energy efficiency code for commercial buildings. The state has a voluntary Building Energy Efficiency Standard (BEES), which sets building energy use standards for thermal resistance, air leakage, moisture protection, and ventilation (Alaska Housing Finance Corporation, 2022a). However, BEES was not implemented until 1992. The current iteration of BEES is based on the 2018 IECC and ASHRAE 62.2 2016 with Alaska-specific amendments.

Improving the energy efficiency of the commercial building stock should reduce building energy consumption and lead to reduced energy costs and carbon emissions from the building sector. For this study, two representative buildings were modeled as if their building envelopes were constructed to the energy efficiency standards of ASHRAE 90-1975 and ASHRAE 90.1-2001 to determine how energy efficiency standards of different eras affect energy consumption for space heating in cold climates.

ASHRAE Standard 90.1 is the energy standard for buildings except low-rise residential buildings, which includes new commercial buildings. ASHRAE 90.1 provides minimum requirements for the energy efficient design of new buildings and covers the building envelope, heating, ventilation, and cooling (HVAC) equipment and system, lighting, water heating, and power. It is the reference standard for the U.S. Energy Policy Act. The standard was first issued in 1975 and has been revised, expanded, and updated numerous times over the years. The current standard was adopted in 2019.

This study is novel because it assesses the impact of building energy efficiency standards on space heating in actual buildings located in a cold climate and ground truths the models with actual heating data. Many previous studies examining the impacts of improved building energy efficiency standards in cold climates focus on prototype buildings (Kneifel, 2013; Lui, Rosenberg, and Athalye, 2018; Nambiar, Hart, and Xie, 2019).

Building Descriptions

The representative buildings used in this analysis include a child development center and an office building described below.

Child Development Center. The child development center is a 7,187 square foot building constructed in 1983. The building is occupied by 50 to 76 people from 5:30 am to 6:30 pm Monday through Friday. The exterior walls are 2x6 wood framing with 16-inch on center spacing and R-19 fiberglass insulation. The roof is constructed of standing seam metal roofing on a wood truss frame with R-38 fiberglass insulation. The foundation is concrete slab-on-grade with two inches of rigid insulation around the perimeter. Most of the windows in the building are double paned. The doors are thermally broken insulated hollow metal.

The building has a designed heat load of 262,000 Btu per hour and is heated with steam from a district heating system. The heat is distributed through hydronic baseboard units. Entries and doorways are heated with hydronic cabinet unit heaters, and heat for mechanical and utility spaces is provided by unit heaters. The hydronic heating systems are served by a series of paired pumps. A steam heat exchanger provides domestic hot water for the building.

Office Building. The office building is 20,136 square feet and was constructed in 2014. The building met the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Gold standard in 2017. The building is typically occupied by 70 to 100 people and has a maximum occupancy of 220 people. It is typically occupied from 5:30 am to 5:00 pm Monday through Friday. The exterior walls are metal stud filled with R-25 fiberglass insulation and have two different finishes. The first finish is an exterior insulated metal panel. The second finish is a concrete masonry unit veneer on top of rigid insulation. The roof has two sections. The lower roof is low-sloped membrane over R-90 rigid insulation and metal deck. The higher roof has a steeper slope and is standing seam metal over R-90 insulation and metal deck. The foundation is concrete slab-on-grade over three inches of rigid insulation. Most of the windows throughout the building are thermally broken aluminum storefront systems and are triple paned and argon filled. The doors are thermally broken insulated hollow metal commercial doors.

The building has a designed heat load of 948,500 Btu per hour. The building is heated using steam from a district heating system. Heating is distributed through the building via low temperature radiant slab on the first two floors of the building. Secondary heating is provided through hydronic baseboard units. Entries and doorways are heated with hydronic cabinet unit heaters. Mechanical and utility spaces are heated with unit heaters. The hydronic heating systems are served by a series of paired pumps. A steam heat exchanger provides domestic hot water for the building.

METHODS

ASHRAE Level 2 Audits were conducted on both buildings by professional energy auditors in mid-January 2022. The energy audits included analysis of the building shell, interior and exterior lighting systems, heating, ventilation, and cooling systems, as well as plug loads. AkWarm Energy Modeling Software (AkWarm) was used to generate As-Is constructed energy models of both buildings. AkWarm is an open-source energy analysis software owned by the Alaska Housing Finance Corporation that was originally released in 1996 (Alaska Housing Finance Corporation, 2022b). It is designed to be used for energy design, retrofits, and determining energy ratings. The software allows the user to analyze building energy use, calculate design heat load, compare energy performance and energy costs, compute the savings associated with energy efficiency measures, and show compliance with BEES.

AkWarm simulates the thermal performance of a building's envelope and models the HVAC system and central plant. The software uses typical meteorological year (TMY3) weather profiles. The estimated energy use predicted by the AkWarm As-Is model for each building was compared to the actual steam use of the building to assess the accuracy of the models. Then, for each building, the modeled building envelope components (e.g., floors, walls, windows, doors, roof, and air tightness) were adapted, first to meet the building standards outlined in ASHRAE 90-1975 and then again to meet the standards outlined in ASHRAE 90.1-2001. The building steam use was estimated using these models, while holding the building mechanical systems constant. The energy efficiency standard for each building envelope component and its associated U-value used in the As-Is, ASHRAE 90-1975, and ASHRAE 90.1-2001 AkWarm building energy models are displayed in Table 1 for the child development center and Table 2 for the office building.

Table 1. Building Energy Code Comparison for Child Development Center

Building Envelope Component		As-Is		ASHRAE 90-1975		ASHRAE 90.1-2001	
		Description	U-Value	Description	U-Value	Description	U-Value
Floors	Center	Slab-on-grade; No insulation	0.000			Slab-On-Grade Floors > Unheated: R-10 for 24 in	0.100
	Perimeter	Slab-on-grade, Insulated edge - 2-inches of EPS (15 psi) for 48 in	0.106	Slab-on-grade, Unheated: R-9.5 minimum to 24-inches	0.105	Slab-On-Grade Floors > Unheated: R-10 for 24 in	0.100
Walls	Wall (A)	Single-stud, Siding+Plywood sheathing, 2x6 (16" OC) , R-19 batt	0.062	Type B, <= 3 Stories: U-0.20 maximum	0.200	Walls, Above Grade > Wood Framed and Other: R-13+R-7.5 ci minimum	0.051
Windows	Window (A)	Triple, 1 low-e, reinforced vinyl frame; 3/8" gap; Air	0.370	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Vertical Glazing, % of Wall > 20.1-30.0%: U-0.35 maximum	0.460
Doors	Door (A)	Entrance; Metal; honeycomb core; no glass	0.556	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Opaque Doors > Swinging: R-2 minimum	0.500
	Door (B)	Entrance; Metal; Polyurethane core; quarter lite	0.250	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Opaque Doors > Swinging: R-2 minimum	0.500
Roof	Roof (A)	I-Beam (16" OC); R-38 Batt	0.025	Type B: U-0.06 maximum	0.060	Roof > Attic and Other: R-38 minimum	0.027

Air Tightness		BDT@75Pa (8649 CFM, 0.57 flow exp)		Windows 0.5 cfm/ft2; Door: 11 cfm/ft		Fenestration/Doors: 0.4 cfm/ft2	

Table 2. Building Energy Code Comparison for Office Building

Building Envelope Component		As-Is		ASHRAE 90-1975		ASHRAE 90.1-2001	
		Description	U-Value	Description	U-Value	Description	U-Value
Floors	Center	Slab-on-grade, Insulated Edge - 5" PISO + 2" EPS	0.021			Slab-On-Grade Floors > Unheated: R-10 for 24 in	0.100
	Perimeter	Slab-on-grade, 3" EPS for 48 in	0.021	Slab-on-grade, Unheated: R-9.5 minimum to 24-inches	0.105	Slab-On-Grade Floors > Unheated: R-10 for 24 in	0.100
Walls	Wall (A)	Metal stud, Siding, R-25 Batt + PISO 5" (R-55 nominal)	0.019	Type B, <= 3 Stories: U-0.20 maximum	0.200	Walls, Above Grade > Steel Framed: R-13+R-13 minimum	0.064
	Wall (B)	Concrete (4"), R-25 Batt + PISO 5" (R-55 nominal)	0.019	Type B, <= 3 Stories: U-0.20 maximum	0.200	Walls, Above Grade > Steel Framed: R-13+R-13 minimum	0.080
Windows	Window (A)	Triple, 2 low-e (U-value 0.35; SHGC 0.35)	0.350	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Vertical Glazing, % of Wall > 40.1-50.0%: U-0.35 maximum	0.350
	Window (B)	Kalwall; Quad, 2 low-e (U-Value 0.1; SHGC 0.12)	0.100	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Vertical Glazing, % of Wall > 40.1-50.0%: U-0.35 maximum	0.350
Doors	Door (A)	Entrance: Metal: Polyurethane core; metal edge	0.200	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Opaque Doors > Swinging: R-2 minimum	0.500
	Door (B)	Door, Triple, 2 low-e, U-value 0.35; SHGC 0.35	0.350	Whole wall assembly including Windows and Doors: U-0.20 maximum	0.200	Opaque Doors > Swinging: R-2 minimum	0.350
Roof	Roof (A)	Low-sloped Roof, 5" EPS + 13" EPS + 5" EPS (R-90)	0.011	Type B: U-0.06 maximum	0.060	Roof > Insulation Entirely above Deck: R20 ci minimum	0.048
	Roof (B)	Steep-sloped Roof, 5" EPS + 13" EPS + 5" EPS (R-90)	0.011	Type B: U-0.06 maximum	0.060	Roof > Insulation Entirely above Deck: R20 ci minimum	0.048
Air Tightness		BDT@75Pa (7695 CFM, 0.6 flow exp)		Windows 0.5 cfm/ft2; Door: 11 cfm/ft		Fenestration/Doors: 0.4 cfm/ft2	

Actual Building Energy Use

The actual steam load of each building was measured using steam condensate meters from October 2020 through September 2021. A total of 13,278 heating degree days is associated with this period. Figure 1 shows the daily steam load of each building in thousands of Btu. Steam use peaks during the winter months when space heating demand is at its greatest and is lowest during the summer months. Note the missing data for the office building during June, July, and part of August. The child development center had an annual steam load of 656,000 pounds and the office building had an annual steam load of 1,543,000 pounds. This translates to an annual steam load of 91 pounds per square foot for the child development center and 77 pounds per square foot for the office building.

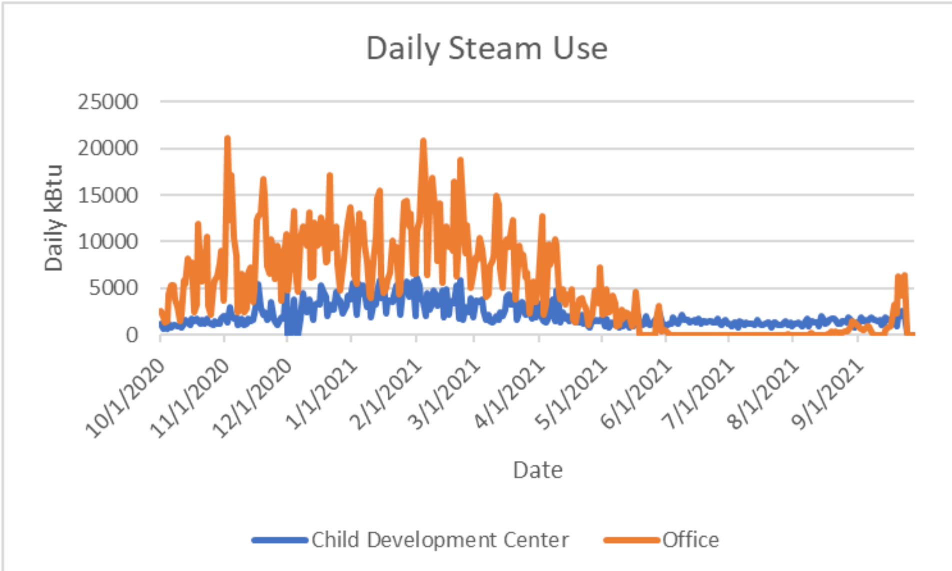

Figure 1 Daily steam use for the child development center and the office building.

RESULTS

To assess the accuracy of the As-Is models, the estimated steam load from the As-Is model was compared to the actual steam load for each building. The actual and modeled monthly steam loads for the child development center are compared in Table 3. The model overestimated steam use during the winter months but underestimated steam use during the summer months. The model most accurately estimated steam use for January through March and was least accurate for the months of October and November. The model overestimated annual total steam use by 12%.

Table 3. Child Development Center Monthly Steam Use

Month	Actual Steam Use (kLbs)	Modeled Steam Use (kLbs)	Percent Difference (%)
January	109	126	16
February	84	100	19
March	71	83	17
April	48	42	-13
May	34	24	-29
June	37	15	-59
July	31	15	-52
August	36	19	-47
September	46	31	-33

October	32	62	94
November	54	100	85
December	74	118	59
Annual Total	656	735	12

The actual monthly steam loads for the office building are compared to the modeled steam loads in Table 4. The model most accurately estimated the steam use for February through April. It was least accurate for the months of June and July, which have the most missing data and the lowest steam loads. The model overestimated annual total steam use by 16%.

Table 4. Office Building Monthly Steam Use

Month	Actual Steam Use (kLbs)	Modeled Steam Use (kLbs)	Percent Difference (%)
January	232	318	37
February	272	260	-4
March	201	222	10
April	122	115	-6
May	42	55	31
June	0.3	8	2567
July	0.1	8	7900
August	7	8	14
September	65	75	15
October	132	166	26
November	222	260	17
December	248	301	21
Annual Total	1543	1796	16

At the time the child development center was constructed in 1983, ASHRAE 90-1975 was still the most recent building energy efficiency standard. Modeled as it is constructed, the building uses 35% less steam annually than it would use if it was constructed to the standards for the energy efficiency of building envelopes set forth in ASHRAE 90-1975, as is seen in Figure 2. However, the building uses 4% more steam annually than it would use if it was constructed to the standards of ASHRAE 90.1-2001.

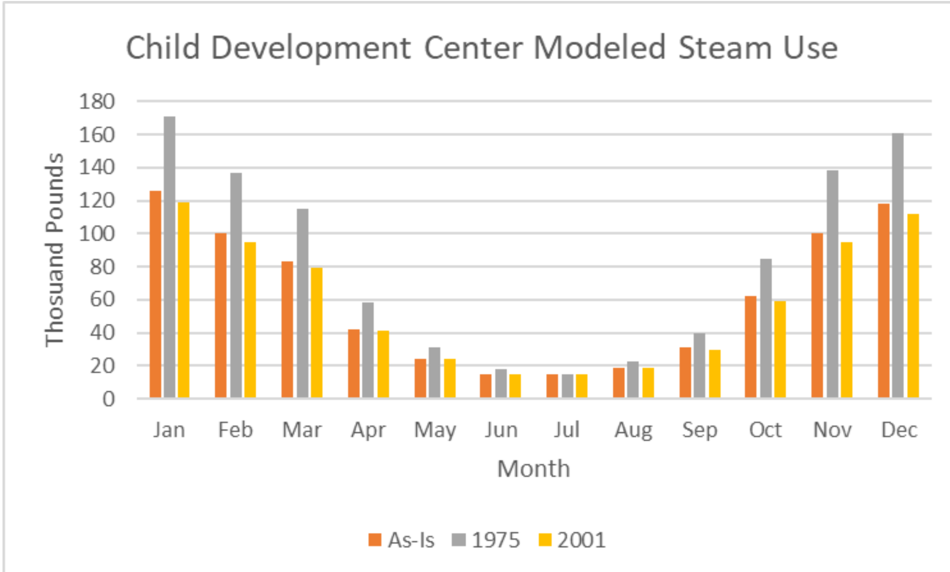

Figure 2 Estimated monthly steam use for the child development center from the As-Is, ASHRAE 90-1975, and ASHRAE 90.1-2001 building energy models.

The office building exceeds the energy efficiency standards set forth in ASHRAE 90.1-2013, which was in place during the time of its construction in 2014. Modeled as it is constructed, the building uses 86% less steam annually than it would use if it were constructed to the energy efficiency standards for building envelopes set forth in ASHRAE 90-1975 and 12% less steam annually if it was constructed to the standards in ASHRAE 90.1-2001 (12% less), as is seen in Figure 3.

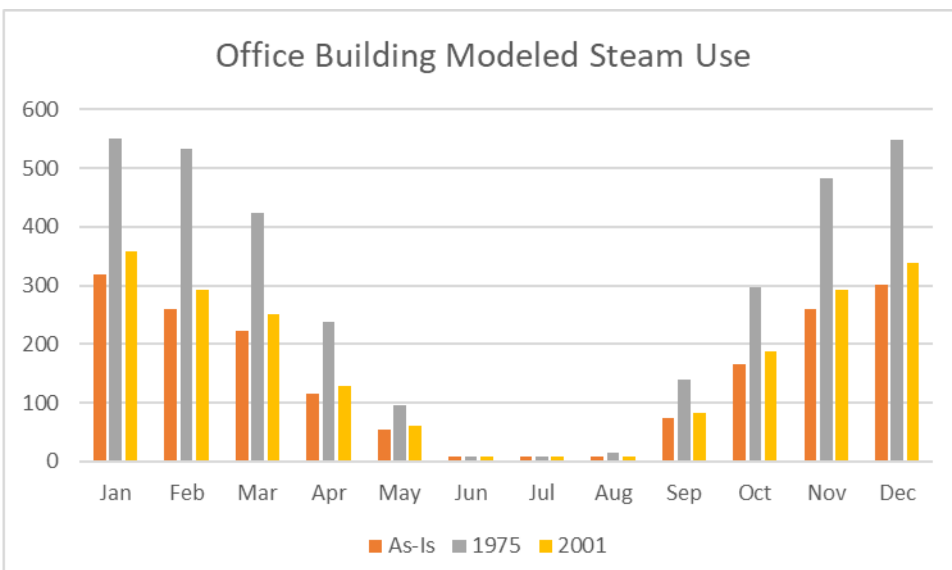

Figure 3 Estimated monthly steam use for the office building from the As-Is, ASHRAE 90-1975, and ASHRAE 90.1-2001 building energy models.

CONCLUSION

This study examined how the building envelop energy efficiency standards of different eras impact the energy used for space heating in two representative buildings in a cold climate region. Professional energy audits were conducted on the buildings, and As-Is energy models of the buildings were generated. The As-Is models were ground truthed with actual steam use data. Then, the models were adapted so their building envelopes met the energy efficiency standards set forth in 1975 and 2001, and the steam use of the buildings was again estimated. The results indicated that more stringent energy efficiency standards lead to a reduction in steam used for space heating. Increasing the energy efficiency of buildings that are currently heated with fossil fuels will reduce energy consumption, thereby leading to reduced energy costs and carbon emissions from the building sector.

ACKNOWLEDGMENTS

This material is based upon work supported by the Broad Agency Announcement Program and the Cold Regions Research and Engineering Laboratory (ERDC-CRREL) under Contract No. W913E521C0017.

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