Energy Simulation Study of Efficient Construction Materials for Cold Climate Homes

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Abstract.

The Residential sector in Alaska accounts for about 8% of the total national energy consumption. Space heating accounts for 41% of total residential energy consumption. Many studies are conducted to model building energy consumption in different climates of world. However, there are very few studies about the most efficient building constructions for Alaska climate. There are four climate zones in Alaska, based on annual and monthly averages of temperature and precipitation. These are, arctic zone, continental zone, maritime zone and transitional zone. In this study, heating energy consumption of a single detached house in Anchorage Alaska which is in edge of maritime and transitional zones, is modelled by means of simulations with eQUEST software. The results of simulations show that most energy efficient roof, wall and door construction material is wood. Dark colored roof and wall are estimated to consume 2% less energy for heating compared to light colored ones. Also, with the application of roof insulation 3-13% and with the application of wall insulation 4-12% energy saving is obtained. Most energy efficient window glazing is concluded to be 12 mm argon filled triple glazing. In addition to window glazing, 7-8% saving is obtained with the application of wood and fiber window frames. Besides these calculations effect of direction of windows and doors on heating energy consumption are also calculated.

Keywords: Building Energy Simulation, Alaska, eQUEST, Cold Climate

1 Introduction

In the Arctic region, the temperature reaches extremely low values. There are great winds, and storms that have a significant effect on the heat loss though the house envelopes. The latitude and longitude of Anchorage is 61.2 N and 149.9 W [1]. Mean annual temperature of Anchorage is 2.2 °C and January is the coolest month with a mean temperature of -9.5 °C [2]. Due to the extremely cold winters there exists high temperature difference between indoors and outdoors of the buildings. Also, limited solar radiation during winter increases energy need for heating. Achieving building materials and energy supply for heating is difficult in Arctic regions. For these reasons decreasing energy consumption becomes significant issue that can be done by developing new construction technologies with larger focus on energy efficiency [3].

Average price of electricity for residential sector of Alaska is 5th among 54 states in USA [4]. Average price of natural gas for residential sector of Alaska is 30th among 54 states in USA [5]. Despite the high energy price in Alaska, due to high energy requirement, Alaska is 3rd by total energy consumption per capita in USA [6]. Residential sector in Alaska accounts for about 8% of the total energy consumption [7]. Increase in energy consumption results in increases of associated CO_2 emission. CO_2 emission of residential sector in Alaska resulted from fossil fuel consumption between 1980 and 2013 [8] show that CO_2 emission especially from natural gas is increasing. Therefore, it is very important to decrease energy consumption for space heating in residential sector of Alaska, due to high energy consumption per capita, expensive energy prices, high rate of energy consumption for space heating and increasing CO_2 emission.

There are very few literature published about energy efficiency in single detached buildings in the Arctic region [9]. A research conducted to calculate optimum room temperature for cold climates and showed that, air temperature control strategy has an important effect on energy consumption and the best air temperature control strategy is to provide air constantly at 20 ºC [10]. Another study is developed to compare the energy performance of six high performance wall assemblies for Canadian Arctic Homes [3]. Heat gain from windows is described in detail in a PhD thesis for Arctic areas [11]. Another study is conducted to compare the potential of energy saving in detached and semi-detached wooden houses in Arctic Greenland. Results showed a current energy consumption of 214 to 383 kWh/m^2-year for heating [9]. Grey-box modeling of the heat dynamics of an apartment in a highly insulated test building located in the Arctic is presented in a study [12]. Another study showed that orientation effects a building's energy load especially in newer, better-insulated homes [13].

A PhD study is conducted in University of Fairbanks Alaska and showed that average energy rating for residential properties is 3 Stars and mean age of properties at sale is 38 years old in Anchorage, Alaska. The average energy use for Anchorage homes built in the 1980s is 457 kWh/m^2 (145,000 Btu/ft^2) compared to 343 kWh/m^2 (109,000 Btu/ft^2) for homes built during the 1990s [14]. Energy rating for Anchorage and Fairbanks homes and their energy consumption is shown in Fig. 1.

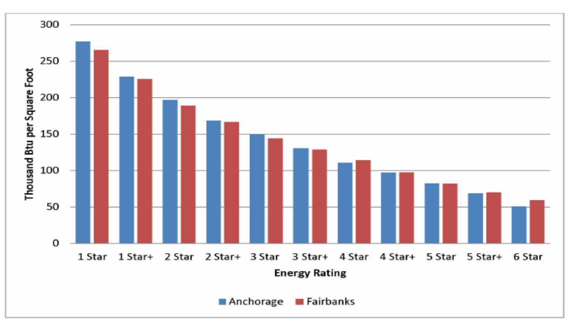

Fig. 1. Energy rating and their energy consumption for Anchorage and Fairbanks homes [14]

It's clear from Fig. 1 that total energy consumption is changing from 150 kWh/m^2 (50.000 Btu/ft^2) to 850 kWh/m^2 (270.000 Btu/ft^2) [14]. Therefore energy consumption for heating is changing between 60 kWh/m^2 and 340 kWh/m^2.

The purpose of this study is to model heating energy consumption of a single detached house located in Anchorage, Alaska theoretically. Then, due to the high importance of energy efficiency in arctic area and high ratio of energy consumed for heating, second main purpose is to determine most energy efficient material types for constructions resulting in heat loss by applying many scenarios.

2 Methodology

This section contains information about the characteristics of the model house, methodology followed during model development, scenario application and energy efficiency calculations of the results of the scenarios.

2.1 Properties of the Model House

Model house is located in Anchorage, Alaska. House is single floor and single detached. Total heated area of the house is 232 m^2. Heating system is baseboard electricity system with 22 kW capacity and heating set point is 20 ºC.

Total Solar Absorptance is the ratio of the total solar energy absorbed by the object to the total solar energy falling on the object [15]. In this study color of the roof and outer walls are mid grey with an absorptance value of 0,6 [15]. There is R-38 insulation on roof. In addition, there is 1,25 cm fiber exterior insulation and R-19 additional insulation on outer walls. Ground of the house contacts to the earth and ground floor is made of 15 cm concentrate and R-10 insulation. 15% of each wall from floor to ceiling is made of windows. Properties of doors and windows are given in Table 1.

Table 1. Properties of doors and windows

	Construction	Ht (m)	Wd (m)	N	S	E	W
Door	Steel, Polurethane core	2	0,9	1	1	-	-
Window	Double clear, 6 mm glazing, 12 mm air	1,2	2,14	15%	15%	15%	15%
Frame	Aluminum		0,03				

2.2 Modelling of Energy Consumption of Test House

The hourly energy consumption model of the house was created by using the characteristics given in section 2.1. eQUEST simulation software is used for model development. Type of weather data used in this study is TMY2 (Typical Meteorological Year version 2) data which is named as anchorak.bin for Anchorage [16]. After completing the model, energy consumption for heating is estimated by eQUEST simulation software [17].

2.3 Scenarios

Envelope improvement scenarios were evaluated by using the hourly heating energy demand model created in eQUEST software. U values of constructions and materials of all current constructions are summarized in Table 2.

Table 2. U values of materials and constructions in model house

Case	Current Construction	U value of Const., W/m^{2}°-K	U value of Material, W/m^{2}-K
Roof Construction	Wood Standard Frame	0,164	9,46
Roof Exterior Insulation	No Insulation	0,164	9,46
Walls Insulation	1,25 cm fiber sheathing	0,319	4,27
Ground Floor	Earth Contact	1,167	1,167
Door Material	Steel, Polyurethane	4,650	4,650
Window Glazing	Double 12 mm air filled 6 mm glazing	2,100	2,100
Window Frame	Aluminum	15,780	15,780

Technical data for Window/door direction scenarios are summarized in Table 3 and U values of constructions and materials of suggested envelope improvement scenarios are summarized in Table 4.

Table 3. Door and window direction scenarios

Case	Current Property				Scenario Code	Suggested Property			
	N	S	E	W		N	S	E	W
					DD1	-	-	1	1
					DD2	2	-	-	-
Door Direction	1	1	-	-	DD3	-	-	2	-
					DD4	-	-	-	2
					DD5	-	2	-	-
					WD1	45%	15%	-	-
					WD2	-	-	45%	15%
					WD3	-	-	15%	45%
Window Direction and Percentage	15%	15%	15%	15%	WD4	-	-	30%	30%
					WD5	30%	30%	-	-
					WD6	15%	45%	-	-
					WD7	5%	45%	5%	5%

Table 4. U values of materials and constructions for suggested scenarios

Case	Sce. Code	Suggested Construction	U value of Const., W/m²°-K	U value of Material, W/m²°-K
Roof Construction	RC1	Metal frame	0,254	0,283
	RC2	10 cm Concentrate	0,274	
	RC3	20 cm Concentrate	0,267	
	RC4	Wood scissors Truss	0,187	0,203
	RC5	Wood advanced frame	0,170	0,180
Roof Exterior Insulation	RI1	2,5 cm polystyrene	0,148	0,0424
	RI2	2,5 cm polyurethane	0,135	1,367
	RI3	2,5 cmpolyisocyanurate	0,132	0,799
	RI4	5 cmpolyisocyanurate	0,112	0,396
Walls Insulation	WI1	2,5 cmpolystyrene	0,274	1,367
	WI2	2,5 cmpolyisocyanurate	0,238	0,799
	WI3	2,5 cm polyurethane	0,222	0,602
	WI4	5 cmpolyisocyanurate	0,180	0,396
Ground Floor	GF	Construction: 2,5 cm Plywood, R-30 batt exterior insulation	1,020	
Door Material	DM1	Steel, polystyrene core	4,650	4,650
	DM2	Wood, hollow core flush	3,910	3,910
	DM3	Wood, solid core flush	3,170	3,170
Window Glazing	WG1	Double Clear 3 mm, 6 mm Air	3,2	3,2
	WG2	Double Clear 6 mm, 12 mm Argon	1,9	1,9
	WG3	Triple Clear 3 mm, 6 mm Air	2,19	2,19
	WG4	Triple low-E Film 3 mm, 6 mm Air	1,81	1,81
	WG5	Triple low-E Film 6 mm, 12 mm Air	1,23	1,23
	WG6	Double low-E Clear 6 mm, 12 mm Air	1,96	1,96
	WG7	Triple Clear 3 mm, 12 mm Air	1,79	1,79
	WG8	Triple Clear 3 mm, 12 mm Argon	1,64	1,64
Window Frame	WF1	Wood/Vinyl, Oper, Ins Spacer	1,9	1,9
	WF2	Ins Fiberglass/Vinyl, Oper, Ins Spacer	3,01	3,01

Suggested constructions listed in Table 4 are applied to the house envelope of the model and heating energy consumption is recalculated for each case. In addition to envelope construction improvement scenarios, effect of color of envelope and door/window direction on heating demand is determined. Heating energy consumption of the house is calculated for "paperbank" color (Abs=0,4) and "night sky" color (Abs=0,9) wall (WCo1, WCo2) and roof (RCo1, RCo2).

Heating demand of the house is calculated for heating set point of the heating system which is normally 20 ºC. Heating energy consumption of the house is also calculated in the case of 21 ºC and 22 ºC heating set points. Heating demand is also calculated for 2 and 3 number of floors keeping the heated area constant. Finally heating demand is calculated in the case of open crawl space ground floor.

3 Findings

According to the simulation results, energy consumption for heating of the house is estimated as 17,53 MWh/year, energy consumption for heating per heating area is estimated as 76 kWh/year-m^2 by eQUEST. According to the study conducted in University of Fairbanks Alaska [14] this results show that model house has 5star+ energy rating due to its strong insulation, less infiltration and young age compared to old houses.

3.1 Envelope improvement scenarios

Results of suggested envelope improvement scenarios in Table 3 and Table 4 are given in this section. Heating energy consumption of the model house is shown as "RH" in figures.

Effect of door, window and window frame materials on heating energy consumption are analyzed in the scope of envelope construction improvement scenarios. Results obtained by the retrofit of door material (DM1, DM2, DM3), window glazing (WG1-WG7) and window frame (WF1, WF2) listed in Table 3 are given in Fig. 2.

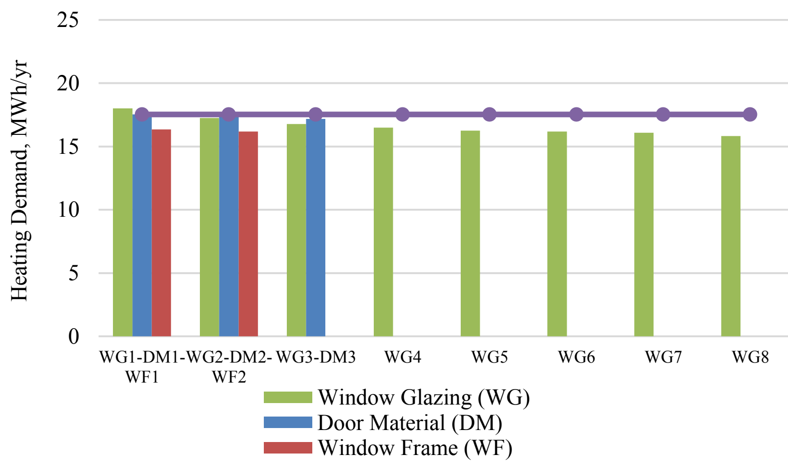

Fig. 2. Heating demand for door, window and window frame material scenarios

Most efficient window glazing is 12 mm Argon filled 3 mm clear triple glazing (WG8) and 10% energy saving obtained compared to 12 mm air filled 6 mm double glazing with this scenario. In addition to glazing, window frame material is very important for cold Alaska climate. In the case of application of wood and fiber frame 7% and 8% saving is obtained compared to aluminum window frame

Results obtained by the retrofit of roof construction (RC1-RC5), application of wall insulations (WI1-WI4) and roof insulations (RI1-RI5) listed in Table 4 are given in Fig. 3.

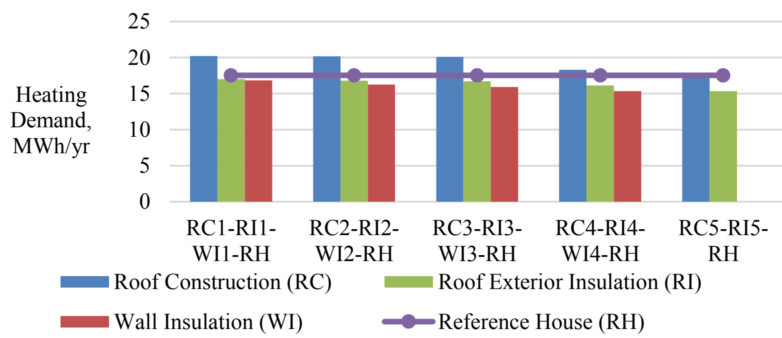

Fig. 3. Heating demand for roof and wall construction material scenarios

According to Fig. 3 to most efficient roof construction for Anchorage climate is Wood Frame which is the construction used in reference house. In the application of RC4 and RC5 scenarios, consumed energy is very close to the energy consumption of reference house. However in the application of metal and concentrate constructions on the roof, 15% more energy is consumed for heating compared to wood roof construction. Therefore, wood material is concluded to be the most energy efficient roof material for cold climate houses. After the application of insulation scenarios (RI and WI), polyisocyanurate is found to be the most energy efficient insulation material. 10 cm polyisoc anurate application on the roof is concluded to result in 13%, 5 cm polyisocyanurate on the outer wall concluded to result in 12% energy saving Fig. 3.

3.2 Color of envelope and, door and window direction scenarios

The color of roof and walls are mid grey (Abs=0,6). In the case of application of dark roof and wall (Abs=0,9) 1% energy saving with light roof and wall (Abs=0,4) 1% energy loss with dark roof and wall is obtained. As a result of these scenario applications dark roof and wall color is concluded to be more energy efficient for cold climate buildings.

In the reference house windows are 15% even distributed on outer walls. Window and door rate scenarios are applied to the model. Maximum energy is consumed while window/wall ratio is 45% on North and 15% on South wall and there is no window on other walls (WD-1). Minimum energy is consumed while window/wall ratio is 45% on South wall, 5% on other walls (WD-7). As a results of these scenarios it's concluded that as minimum window area as possible on north side and as more window area as possible on south side results in consumption of minimum energy for heating.

Door direction scenarios resulted in similar to window direction scenarios. Maximum energy for heating is consumed when both doors are directed to north (DD-2) and minimum is consumed when both doors are directed to south (DD-5).

Ground Floor of the reference house contacts to the earth. In the case of application of open crawl space construction, 6% energy loss is obtained. It's concluded from this scenario that earth contact ground floor is more energy efficient compared to open space ground floor.

Thermostat set point is a very important effect on energy consumption for heating. Modelled house thermostat heating is set to 20 ºC. 21 ºC set point resulted in 8% more energy consumption and 22 ºC set point resulted in 17% more energy consumption. In addition to this, 10% more energy in 2 floor, 26% more energy in 3 floor is consumed at constant heated area. Therefore most efficient house type is concluded to be single floor house. Heating set point, number of floor and ground floor type of the reference house is found to be the most energy efficient types. Therefore they are not required to be changed.

4 Conclusions

In this study most energy efficient house constructions and structure is investigated by using eQUEST building energy simulation software for Anchorage, Alaska climate. Energy consumption for heating per heating area is estimated as 76 kWh/year-m^2 which means a 5+ energy class house. After modelling the heating energy consumption of the house, scenarios are applied to the model and energy consumption is recalculated. According to simulation results, 15% more energy is consumed compared to wood construction in the case of the application of metal and concentrate constructions on the roof. As a result of investigating the effect of color on envelope 2% less energy is found to be consumed for heating when the color of the roof and wall is dark compared to light roof color. With the application of different insulation materials on roof and wall polyisocyanurate is found to be the most efficient material. 5 cm polyisocyanurate application on the outer wall resulted in 12% energy saving. Most efficient door material for Alaska houses is concluded to be wood. In addition to this, door directions does not change energy consumption more than 0,3%. Most energy efficient door and window direction is determined to be south. Most energy efficient window glazing is determined as 12 mm Argon filled 3 mm triple glazing and 10% energy saving is obtained compared to12 mm air filled 6 mm double glazing. Frame of model house is aluminum. In the case of application of wood and fiber frame 7% and 8% saving is obtained. Change in thermostat heating set point to 21 ºC caused 8% more energy, to 22 ºC caused 17% more energy consumption compared to 20 ºC. Finally by keeping the total area of the house constant 2 floor house results in 10%, 3 floor house results in 26% more energy consumption for heating. Therefore most efficient house type is concluded to be single floor house.

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