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Energy Efficient Construction Materials for Arctic Homes

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Abstract: Residential sector of Alaska accounts for about 8% of the total national energy consumption. Space heating accounts for 72% of the total residential energy consumption. Many studies are conducted to model building energy consumption in different climates. However, there are very few studies about the most efficient building constructions for Alaska climate. In this study, heating energy consumption of a single detached dwelling in Anchorage and Fairbanks Alaska is modelled by means of eQUEST software. The results show that most energy efficient roof, wall and door construction materials are wood. House with dark colored roof and wall are estimated to consume 2% less energy for heating compared to light colored ones. Most energy efficient window glazing is concluded to be 12 mm argon filled triple glazing. In addition, the effect on the energy consumption of direction of doors and windows is also investigated.

Keywords: Building energy simulation, Alaskan houses, eQUEST, arctic climate

Arktik Evleri için Enerji Verimli Yapı Malzemeleri

Öz: Alaska'da konut sektörü, toplam ulusal enerji tüketiminin yaklaşık % 8'ini oluşturmaktadır. Toplam konut enerji tüketiminin % 72'sini alan ısıtması oluşturmaktadır. Farklı iklimlerde bina enerji tüketimini modellemek için birçok çalışma yapılmıştır. Bununla birlikte, Alaska iklimi için en verimli bina yapıları hakkında az sayıda çalışma bulunmaktadır. Bu çalışmada, Alaska Anchorage ve Fairbanks'daki bir müstakil konutun ısıtma enerji tüketimi, eQUEST yazılımı vasıtasıyla modellenmiştir. Sonuçlar, enerji tasarruflu en fazla çatı, duvar ve kapı inşaat malzemelerinin ahşap olduğunu göstermektedir. Koyu renkli çatı ve duvarları olan konutların açık renkli olanlara kıyasla ısıtma için % 2 daha az enerji tükettiği tahmin edilmiştir. Enerji tasarrufu en yüksek pencere camının, 12 mm argon boşluklu üçlü cam olduğu sonucuna varılmıştır. Buna ek olarak, kapı ve pencerelerin yönünün enerji tüketimi üzerindeki etkisi de araştırılmıştır.

Anahtar kelimeler: Bina enerji simülasyonu, Alaska evleri, eQUEST, arktik iklim

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 dwelling envelopes. Mean annual temperature of Anchorage is 2.2 °C and January is the coolest month with a mean temperature of -9.5 °C (ClimaTemps, 2016). Temperature difference between indoors and outdoors of the buildings is too high that increases the significance of insulation. Also, main heat gain solar radiation is limited during winter. In northern America energy costs are very high due to accessibility only by air, boat or ice roads. Therefore energy saving is a significant issue in arctic area (Cornick et al., 2009).

Alaska was 5th among at electricity price (EIA-Electricity Price, 2016) and 30th at price of natural gas for residential sector among 54 states in USA of by 2016. (EIA-NG Price, 2016). Despite the high energy price in Alaska, due to high energy requirement, Alaska is 3rd by total energy consumption per capita in USA (EIA-AK, 2016). Residential sector in Alaska accounts for about 8% of the total energy consumption and 72% of residential energy is consumed for space heating s (Pride, 2017). Increase in energy consumption results in increases of associated CO_2 emission. Figure 1 shows CO_2 emission of residential sector in Alaska resulted from fossil fuel consumption between 1980 and 2013.

As it is seen from Figure 1, 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, 41% rate of energy consumption for space heating and increasing CO_2 emission.

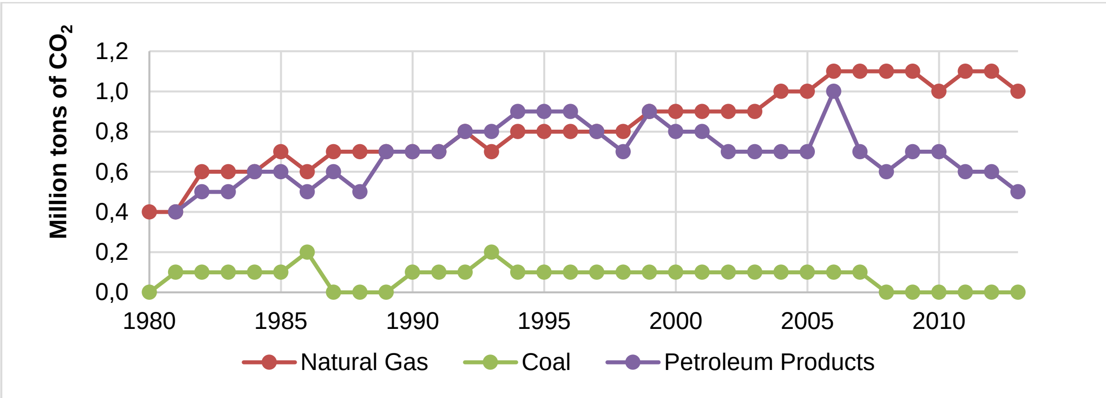

Figure 1. CO_2 emission of residential sector in Alaska (1980-2013) (EIA-CO_2 Emissions, 2016)

There are very few literature published about energy efficiency in buildings in the Arctic region (Bjarløv and Vladykova, 2011). A research conducted to calculate optimum room temperature for cold climates. The result of this study 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 °C (Schiavon and Melikov, 2008). In addition, a study is developed to compare the energy performance of six high performance wall assemblies with typical baseline wall assemblies for Canadian Arctic Homes. Simulation of three buildings and calculation of their energy consumption for heating resulted in least energy consumption for heating with the most highly insulated wall system (Cornick et al, 2009). Heat gain from windows is described in detail in a PhD thesis for Arctic areas (Vladykova, 2011). 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 between 214 and 383 kWh/m^2-a for heating per year (Bjarløv and Vladykova, 2011). 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 (Andersen et al., 2014). A study conducted to analysis the effect of building orientation on heat gain at high latitudes. The results indicate that in new constructed buildings orientation does not effect a building's energy load (Barrett, 2014).

The purpose of this study is to model hourly energy consumption for heating of a single detached dwelling located at Anchorage and Fairbanks Alaska. Then, determine most energy efficient construction types.

2. Materials and Methods

This section contains information on 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. Characteristics of the Model House

Two reference houses with same property are located in Anchorage and Fairbanks Alaska. Houses are single storey, single detached and have 230 m^2 heated area. Heating system is baseboard electricity system with heating set point 20 ºC. The main features of the reference houses are given in Table 1.

Table 1. The main features of the reference house

Feature	Value		Unit
Location	Anchorage		
Building Area	2500		ft^2
Number of Floors	1		
Heating Equipment	Baseboard		
Floor Heights	Flr-To-Ceil	8	ft
	Flr-To-Flr	9	ft
Building Orientation	North		
Heating Set Point	68		ºF
Minimum Design Air Flow	0.5		cfm/ft^2
Capacity of Baseboard Heating System	22		kW
Hot Water Usage	20		gal/person/day
Hot Water Energy Factor	0,87		
Hot Water Supply Water Temp.	110		ºF
Water Inlet Temp	Equals Ground Temp		

Color and insulation properties of the constructions found in the envelope layer of the house are given in Table 2.

Table 2. Construction, colour and insulation properties of the building envelope

	Construction	Color	Insulation
Roof Surfaces	Wood Standard Frame	Medium (abs: 0,6)	R-38 batt
Above Grade Walls	Wood Frame	Medium (abs: 0,6)	2.5 cm Fiber bd sheathing (R-1.3) + R-19 batt
Ground Floor	Earth Contact 9 cm Concrete		vert ext bd, R-10 4ft deep

As seen from Table 2 roof and above grade walls of the dwelling are wood frame. Color of the roof and outer walls are grey with an absorptance value 0.6. 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 dwelling contacts to the earth and ground floor is 9 cm concentrate with R-10 insulation. There are two outer doors made of steel-polyurethane core one facing North and the other facing South. Window glazing is 12 mm air filled 6 mm double glazing. 15% of each exterior wall from floor to ceiling is made up of windows. Window frames are made of aluminum.

2.2. Modelling of Energy Consumption of Test House

Hourly heating model of the houses are created by using the characteristics given. After completing the model, energy consumption for heating is estimated hourly by eQUEST (eQUEST, 2016).

2.3. Scenarios

Envelope improvement scenarios were evaluated for roof, wall, door and windows of the model house.

3. Fingings

According to the simulation results, energy consumption for heating of the dwelling is estimated as 17.530 kWh/yr for Anchorage, 39.960 kWh/yr for Fairbanks. Energy consumption for heating per heating area is estimated as 76 kWh/yr-m^2 and 169 kWh/yr-m^2 respectively.

After modelling the energy consumption for heating of the dwelling, scenarios are applied to the model and energy consumption for heating is recalculated.

3.1. Roof

Existing roof construction of the dwelling is Wood Standard Frame. In the case of changing this construction with the constructions with Metal frame, 10 cm Concentrate, 20 cm Concentrate, Wood scissors Truss and Wood advanced frame (RC-1, RC-2, RC-3, RC-4, RC-5), energy consumption for heating of the dwelling is recalculated and result is given in Figure 2.

Normal energy consumption for heating of the original dwelling estimated by eQUEST is shown as “N” in Figure 2 and other figures. According to Figure 2 most efficient roof construction for Anchorage houses is Wood Frame. In the application of RC-1 and RC-3 (wood advanced frame and wood scissors) as roof material consumed energy is very close to original roof construction that is “wood standard frame”. However in the application of metal and concentrate constructions on the roof consumed energy is 15% more than wood construction.

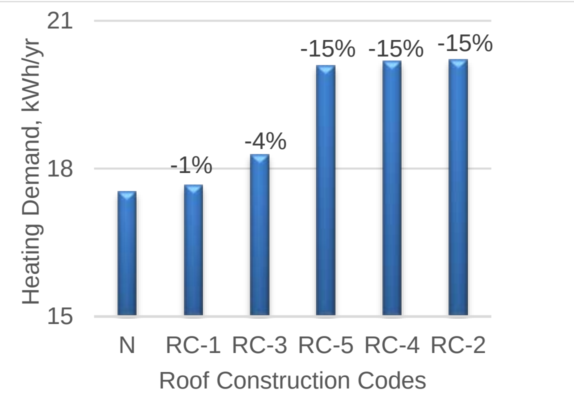

Figure 2. Energy consumption for heating for each roof construction material

Roof color of the dwelling is medium (Abs=0.6). In the case of application of dark roof color (Abs=0.9) energy consumption is calculated as 17.320 kWh/yr and 1% energy saving is obtained. However in the case of application of light roof color (Abs=0.4) energy consumption is calculated as 17.670 kWh/yr and 1% more energy is consumed. Similar results are calculated for Fairbanks. 2% energy saving is obtained in Dark roof color. Therefore dark color is concluded to be more energy efficient for heating Alaskan buildings.

There is no exterior insulation on dwellings roof. In the case of application of the insulations such as 2.5 cm polystyrene, 2.5 cm polyurethane, 2.5 cmpolyisocyanurate and 5 cm polyisocyanurate (RI-1, RI-2, RI-3, RI-4, RI-5), energy consumption for heating of the dwelling is recalculated and result is given in Figure 3.

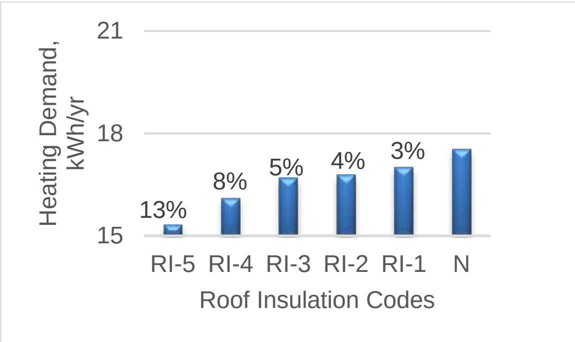

Figure 3. Energy consumption for heating for each roof insulation material

Firstly three kind of insulation materials (polystyrene, polyurethane, polyisocyanurate) are applied on the roof with the same thickness (RI-1, RI-2, RI-3). Then polyisocyanurate is determined to be the most energy efficient insulation material. Polyisocyanurate is then applied on the roof two more times with different thicknesses (RI-4, RI-5). As a result of these applications, 4 inch polyisocyanurate application on the roof is concluded to result in 13% energy saving.

3.2. Wall

Existing outer wall construction of the dwelling is 2×6 Wood Frame. Also, there is ½ in. fibre sheathing insulation as exterior insulation on the outer walls. Colour of the outer walls is medium (Abs=0.6).

In the case of application of dark wall colour (Abs=0.9), energy consumption is calculated as 17.260 kWh/yr and 2% energy saving is obtained. However in the case of application of light wall colour (Abs=0.4) energy consumption is calculated as 17.710 kWh/yr and 1% more energy is consumed. Dark wall colour is concluded to be more energy efficient for Alaskan buildings.

In the case of changing exterior insulation material of outer walls similar to roof insulation polyisocyanurate is calculated to be most energy efficient as in wall insulation. As a result of these applications, its concluded that in the case of application of 2 inch polyisocyanurate on the outer wall, 12% energy saving could be achieved.

3.3. Door

Dwelling has two outer doors one of which is facing to north second is to south. Doors are made of Steel, Polyurethane Core. In the case of changing this construction with wood made doors and chancing the directions of doors energy consumption for heating of the dwelling is recalculated and result is given Figure 4.

According to Figure 4 most efficient door material for Anchorage houses is Wood, Solid Core Flush (DM-2) which results in 2% less heating energy consumption compared to current construction. In addition to this, door directions does not change energy consumption more than 0.3%. Most energy efficient door direction is both of doors facing to east or west.

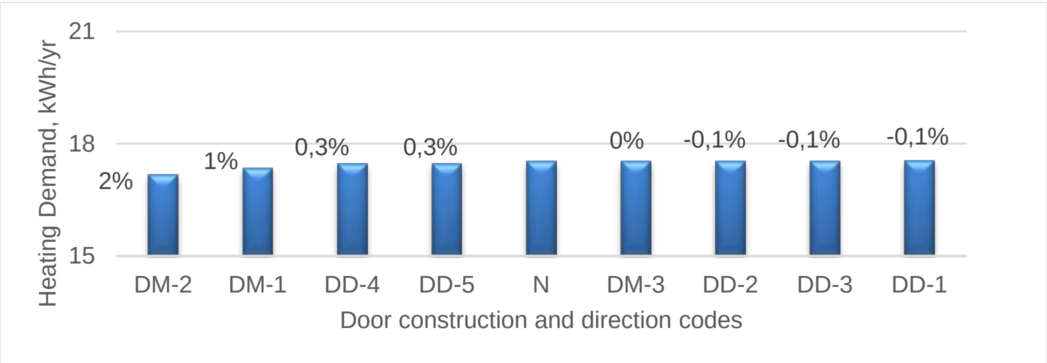

Figure 4. Energy consumption for heating for each door construction and direction

3.4. Window

Window frame of the modelled dwelling is aluminium, window glazing is 12 mm air filled 6 mm double glazing and windows are 15% even distributed on outer walls. In the case of application of different glazing materials energy consumption for heating of the dwelling is recalculated and result for Anchorage and Fairbanks are given in Figure 5 and Figure 6.

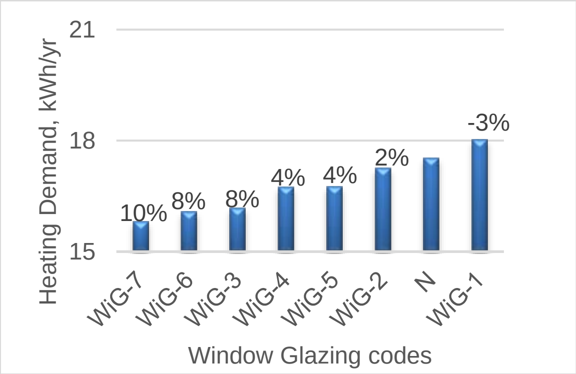

Figure 5. Energy consumption for heating for each window glazing

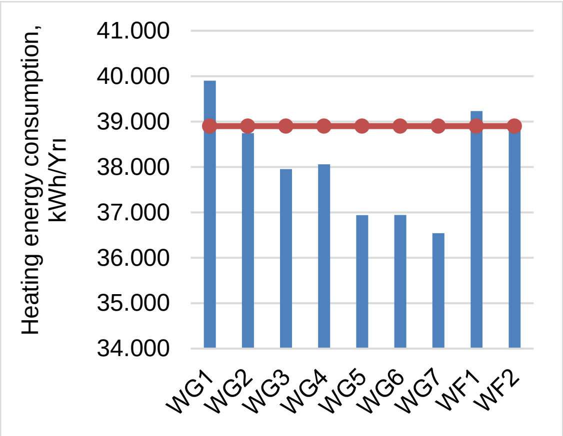

Figure 6. Energy consumption for heating for each window glazing

As it is seen from Figure 5 and Figure 6, most energy efficient window glazing is 12 mm Argon filled 3 mm triple glazing for both cities and results in 10% energy saving compared to the modelled glazing which is 12 mm air filled 6 mm double glazing.

In addition to glazing, window frame material is also very important for cold Alaska climate. In the case of application of different window frame materials provided nearly as much saving as glazing materials. Modelled dwellings uses aluminium frame material. In the case of application of wood and fibre frame 7% and 8% saving is obtained.

Also, direction of window is effective on energy consumption for heating due to the utilization percentage of radiation from sun. In modelled dwelling windows are 15% even distributed on outer walls. In the case of changing the percentage of the windows on walls energy consumption for heating of the dwelling is recalculated and result is given in Figure 7.

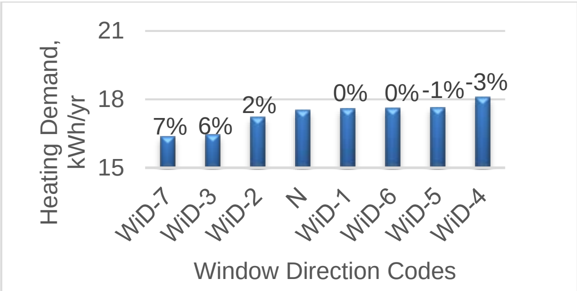

Figure 7. Energy consumption for heating for each window direction

According to Figure 7 maximum energy is consumed while 11.25% of window on North and 3.75% of window on South wall and there is no window on other walls (WiD-4). Minimum energy is consumed while 11.25% of window on South walls, 3.75% of window even distributed on other walls (WiD-7). Energy consumption is lower when windows are even distributed on North and South walls (WiD-2) compared to windows are even distributed on East and West walls (WiD-1).

3.5. Thermostat Heating Set Point

Thermostat heating set point is a very important effect on energy consumption for heating. Modelled dwelling thermostat heating set point is set as 20 ºC. When thermostat heating set point is set to 21 ºC, energy consumption for heating is calculated as 19.000 kWh which results in 8% more energy consumption. When thermostat heating set point is set as 22 ºC, energy consumption for heating is calculated as 20.540 kWh which results in 17% more energy consumption.

4. Result and Discussion

In this study most energy efficient house constructions and structure is investigated by using eQuest building energy simulation software for Anchorage and Fairbanks, Alaska. Energy consumption for heating per heating area is estimated as 76 kWh/yr-m^2 and 169 kWh/yr-m^2 respectively by eQuest. A study is conducted in University of Fairbanks Alaska to determine energy efficiency measures. Its specified in this study that average energy use for Anchorage and Fairbanks homes is 343 kWh/m^2 and 450 kWh/m^2 for average energy class homes built during the 1990s (Pride, 2017). According to energy index in this study modelled house in Anchorage and Fairbanks are found to have 2+ and 2 energy class.

After modelling the energy consumption for heating of the house, different house constructions are applied to the model and energy consumption is recalculated. According to simulation results, wood construction is calculated to be most efficient for both roof, wall and door material. In addition to this, dark color envelope materials resulted 2% less energy consumption. Polyisocyanurate is foung to be most efficient insulation material. 12 mm Argon filled 3 mm triple glazing reduces energy consumption 10% compared to 12 mm air filled 6 mm double glazing.

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