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Survey of occupant behaviour, energy use and indoor air quality in Greenlandic dwellings

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ABSTRACT

In cold arctic regions people usually spend over 70% of their time indoors. The effect of poor indoor air quality on occupants' health and comfort is therefore considerable.

Dwellings in Greenland consume very large amounts of energy (in average over 370 kWh/year per m^2) and in addition, they provide their occupants with poor indoor air quality. A questionnaire survey was performed in the town of Sisimiut-Greenland, which with its location and population represents Greenlandic conditions quite well. The aim of the survey was to investigate the energy consumption and indoor air quality in arctic dwellings and to study the influence of occupant behaviour of people living in arctic climates on energy consumption and indoor air quality. The results have shown that the average electricity consumption is 20% higher than in DK, ventilation systems are insufficient and that the inhabitants often experience cold discomfort in their homes due to their window opening behaviour (to compensate the lack of ventilation) and the age and deficient construction of the buildings.

On the basis of the survey responses, some 80 dwellings were selected for further investigation. Physical measurements of the indoor air quality and observations of occupant behaviour will be performed in the selected dwellings.

1. Introduction

The Greenlandic outdoor climate is cold and dry, so living inside heated buildings results in considerable energy consumption. The Greenlandic building stock includes a large number of dwellings that are more than 40 years old (Bjarlov, Vladykova 2011). The average energy consumption in Greenlandic dwellings is over 370 kWh/year per m^2 floor area, according to available statistics (Statistics Greenland 2011). The high energy consumption (EC) of the Greenlandic buildings is due to a) the extreme weather conditions, b) their poor thermal insulation and untight construction, c) energy price politics (the relatively low price of heating energy does not motivate people to save it; and joint instead of individual heating bills in apartment buildings have the same effect), d) inappropriate occupant behaviour (OB). It has been shown in previous studies (SELIGMAN, DARLEY & BECKER 1978) or the Danish study (Andersen et al. 2009) that OB has a significant effect on the energy consumption of buildings. These studies have never been carried out in such a cold region as Greenland, where the effect is expected to be even larger.

In addition to excessive energy consumption, Greenlandic households face the problem of poor Indoor Air Quality (IAQ). Ventilation equipment is rare, and when present is often limited to an exhaust fan in the bathroom, and possibly some fresh air inlets in a few rooms. The problem is that the latter are often blocked by the inhabitants in order to avoid cold drafts. Exhaust hoods are not always installed over the kitchen stove. With a tradition of long slow cooking, a habit of often drying the laundry indoors, and the need to bring wet outdoor clothing into a living space to dry it, it is often the case that these contributions to indoor humidity are too high for the minimal ventilation rates. Consequently indoor moisture and mould problems are not uncommon in this otherwise "dry country". It is expected that in such a cold region people may often spend more than 70% of their time indoors. The effect of poor IAQ on occupants' health and comfort is therefore considerable.

A comprehensive study was started in March 2011 and is partially presented in this paper. Its main purpose is to monitor the IAQ and EC in Greenlandic dwellings and to study the influence of OB on EC and IAQ in the Arctic. The study is currently taking place in the town of Sisimiut, Greenland. The town has about 5,500 inhabitants living in 2017 dwellings (66% apartments, 34% houses). The study consists of questionnaires and physical measurements in selected buildings.

This paper presents the results of the questionnaire study that was performed in June 2011. During this study some 2017 questionnaires were distributed to every single household in Sisimiut.

2. Methods

2.1 Questionnaire composition

The questionnaire contained questions on the following topics:
- Dwelling characteristics
- Occupants
- Habits
- Indoor climate and preferences
- Maintenance

Most of the questions were multiple choice or matrix questions.

At the end of the questionnaire respondents were asked to supply at least one of the three possible forms of contact information (e-mail, phone number or address) in order to be able to contact them in case they won a lottery. Respondents were also asked to mark if they would like to participate in a follow up study in which 80 dwellings will be selected for objective measurements of IAQ and energy performance.

In order to increase the response rate as much as possible, all respondents participated in a lottery with 3 prizes of 1000 DKK (ca.132 €)

The questionnaire was translated into both official languages in Greenland – Greenlandic and Danish. The translation was double checked by different people to make sure that all misinterpretations were avoided. Greenlandic was used as the main language and Danish translations were underneath the Greenlandic originals, in italics. For better orientation the questionnaire was printed in different colours (green for Greenlandic; blue for Danish).

2.2 Survey

The survey was announced in the local newspaper in the form of an article summarizing the current problems with indoor air quality and their possible consequences. The importance of participation on the survey was highlighted. Posters had been distributed all over the town some days before the survey started.

Envelopes containing the questionnaire and a cover letter explaining the survey were distributed manually into all 2017 addresses in Sisimiut from 14th to 17th June 2011. Participants were asked to deliver the filled questionnaires into one of the collection boxes placed in the major grocery stores in the town. The deadline for handing in the filled questionnaires was set to 27th June. Reminders were sent out by means of short announcements in the local radio 5, 4 and 3 days before the due date, 5 times on each of these days.

2.3 Analysis

Descriptive statistical analysis was performed on the answers to all the questions. The possible links between different variables were tested by means of the Wilcoxon test; Chi squared test and Spearman rank correlation test (Johnson, Miller & Freund 2000). Odds ratios were calculated according to (MORRIS, GARDNER 1988). P-values of 0,05 were used to determine statistical significance.

Statistical software R (Ihaka, Gentleman 1996) and MS Excel were used for the statistical analyses.

3. Results

A summary of the dwelling types to which the questionnaires were distributed and from which they were received is presented in Table 1.

Table 1. Summary of distributed questionnaires

	Apartments	Detached houses	Semidet. houses	Total
Distributed	1338	540	139	2017
Pct.	66.3%	26.8%	6.9%	100%
Received	157	92	21	270
Pct.	58.1%	34.1%	7.8%	100%
Response rate	11.7%	17.0%	15.1%	**13.4%**

3.1 IAQ

The average ranking of the indoor climate was 4,5 (between "Slightly good" and "Good") see Figure 1.

A Wilcoxon test of the difference between perception of the air quality and overall indoor climate yielded a P-value of 0.744, indicating that respondents were most likely to mark the same level of air quality as overall indoor climate. However, when a similar test was applied to perceptions of the thermal climate, a P-value of 0,004 was obtained, indicating that there was a significant number of respondents who considered their thermal conditions to be worse than the overall indoor climate. The result was obtained for the acoustic environment. Respondents living in apartments were more likely to complain about their acoustic environment than respondents from either type of house.
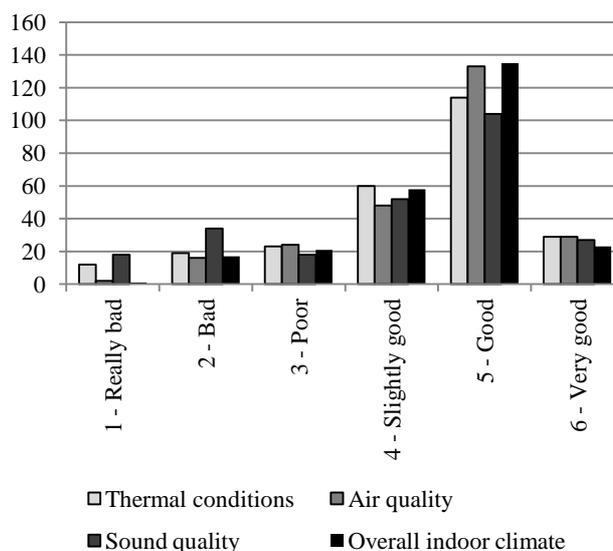

Figure 1. Perceived indoor environment

An analysis of the question "How much do you think of your bills/family health, when you set the indoor temperature/open windows" (Figure 2) showed that respondents care more about their health than costs in both cases (windows and indoor temperature)
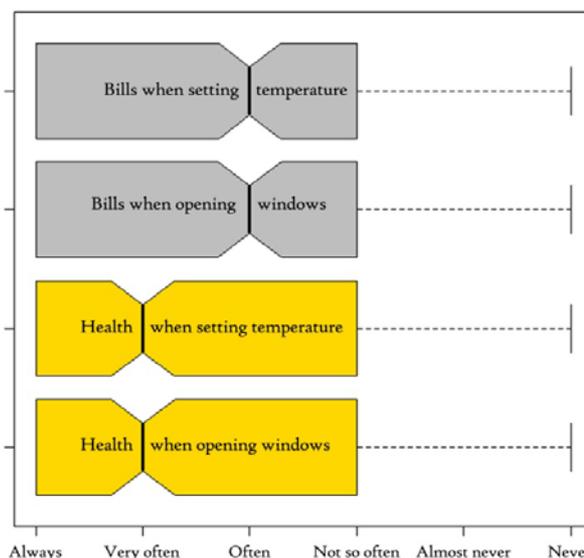

Figure 2. Boxplots for "How much do you think of..." question

Figure 3 shows how important are different options for the respondents. The highest importance was assigned to being able to open/close windows, but obtaining fresh air without experiencing a cold draft or being too cold indoors is also considered to be quite important.
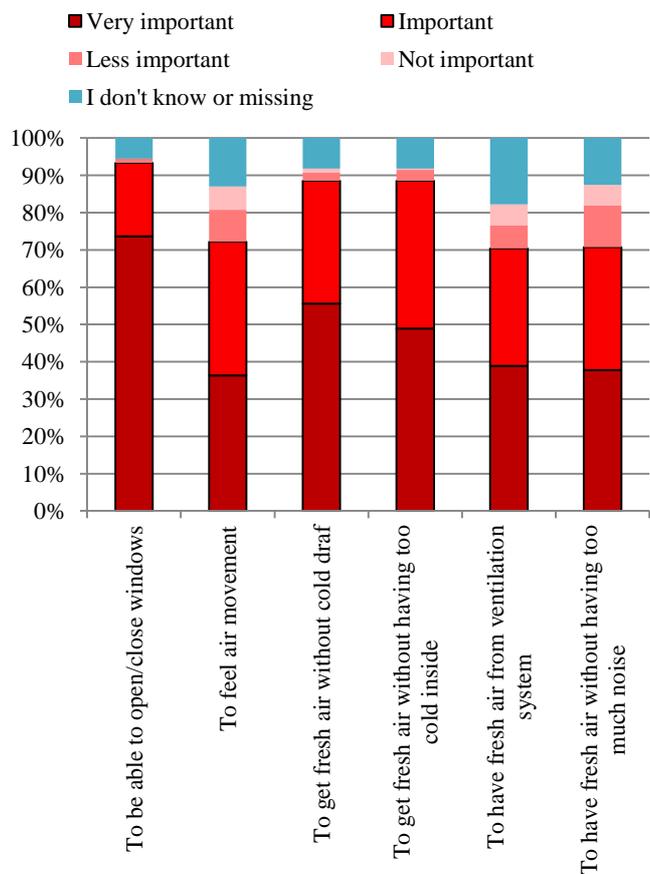

Figure 3."How important is it for you to have the following option in your dwelling?"

Figure 4 presents the problems experienced with indoor climate in respondents' dwellings. Here we see that over 50% of the respondents experience problems with cold discomfort (cold floors, cold draft and cold indoor environment) frequently. Unacceptable condensation on windows was reported in 35% of the dwellings. On the other hand, 62% of respondents reported problems with overheating in summer.

Table 2 presents the odds ratios (OR) for different variables. The respondents from the first group (1.) have OR times the risk of experiencing the cited problem, in comparison with respondents from the second group (2.).
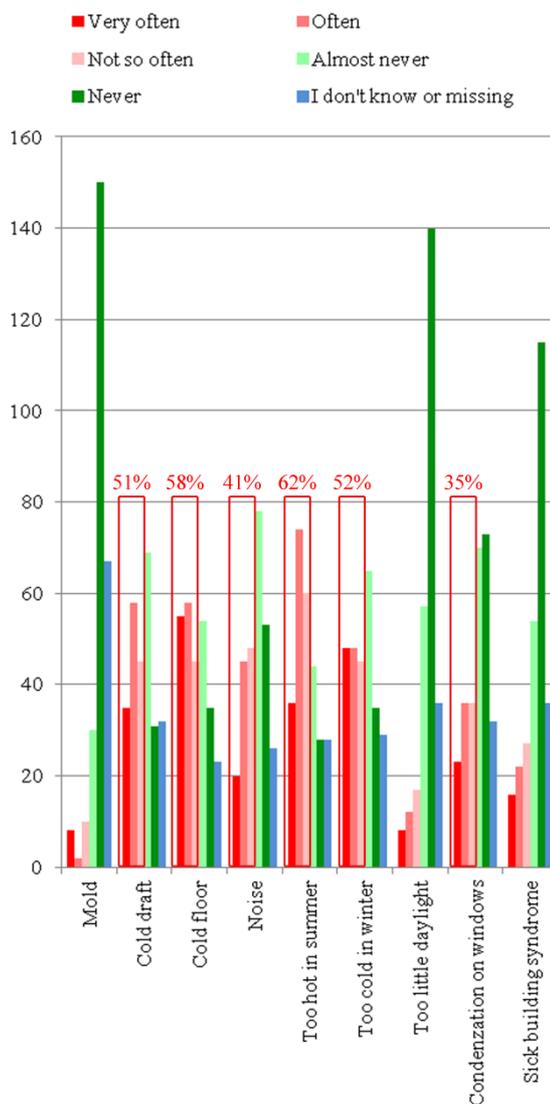

Figure 4. Relative risk

3.2 Habits

3.2.1 Smoking

Overall, 34% of respondents stated that they smoke inside their dwelling. Among respondents having children in their households, 29% smoked (Figure 5).A Chi-squared test yields P=0,1939, indicating that the observed difference was not significant.
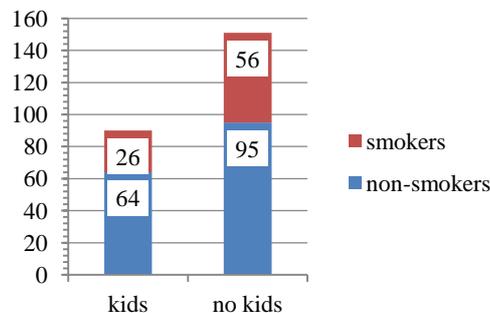

Figure 5. Distribution of smokers among households with and without kids

3.2.2 Windows opening

64% of the respondents reported that they open their windows once or more than once a day even in winter (Figure 6). In addition to draft problems and uncomfortably low temperatures (Table 2) this also leads to increased heat loss.

An analysis of the question: "How would you regulate the temperature in winter if you were too hot?" showed that 10% of the respondents would simply open their windows instead of adjusting the radiator first.
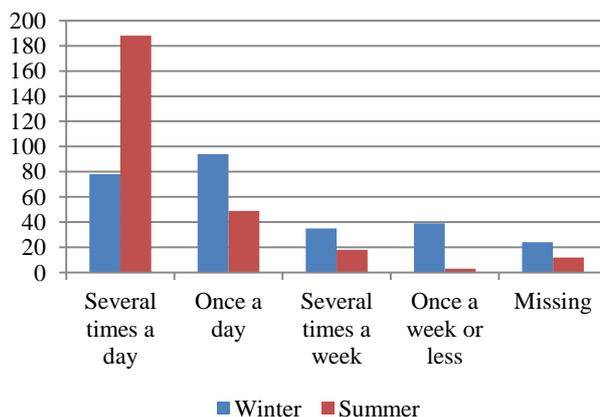

Figure 6. "How often do you open/close windows in your dwelling?"

Table 2. Odds ratios for the selected variables

Problem:		How often you open windows during winter	How often do you use kitchen hood	How often do you use exhaust from bathroom	When was your dwelling built	What type is your dwelling	Who owns the dwelling
		1.Once a day or more	1.Always or almost always		1.Before 1980	1.House	1.Me
		2.Less than once a day	2.Sometimes to never		2.After 1980	2.Apartment	2.Other
Draft	OR	2.1434	NS	NS	NS	0.4377	0.3176
	p-value	**0.0178**	NS	NS	NS	**0.0033**	**0.0001**
	95% conf.int.	1.1329	NS	NS	NS	0.2510	0.1761
		4.0553	NS	NS	NS	0.7633	0.5728
Cold floor	OR	NS	NS	NS	1.9747	0.4289	0.3220
	p-value	NS	NS	NS	**0.0095**	**0.0017**	**0.0001**
	95% conf.int.	NS	NS	NS	1.1776	0.2518	0.1842
		NS	NS	NS	3.3112	0.7306	0.5628
Noise	OR	NS	NS	1.8924	2.3288	0.4218	0.2800
	p-value	NS	NS	**0.0406**	**0.0046**	**0.0054**	**0.0002**
	95% conf.int.	NS	NS	1.0230	1.2890	0.2277	0.1395
		NS	NS	3.5007	4.2075	0.7812	0.5618
Too cold in winter	OR	2.3479	0.4951	NS	1.8125	0.3756	0.2835
	p-value	**0.0086**	**0.0208**	NS	**0.0277**	**0.0005**	**0.0000**
	95% conf.int.	1.2311	0.2713	NS	1.0651	0.2150	0.1574
		4.4780	0.9033	NS	3.0843	0.6560	0.5105
Condensation on windows	OR	NS	NS	NS	NS	0.5022	0.4032
	p-value	NS	NS	NS	NS	**0.0321**	**0.0086**
	95% conf.int.	NS	NS	NS	NS	0.2659	0.2022
		NS	NS	NS	NS	0.9486	0.8040
Sick Building Syndrome	OR	NS	0.2630	NS	NS	NS	0.4066
	p-value	NS	**0.0003**	NS	NS	NS	**0.0311**
	95% conf.int.	NS	0.1240	NS	NS	NS	0.1760
		NS	0.5579	NS	NS	NS	0.9394

3.2.3 Home appliances

- ■ Kitchen Hood - when cooking
- ■ Pot lid - when cooking
- ■ Exhaust from bathroom - when taking a shower
- ■ Open window - when taking a shower
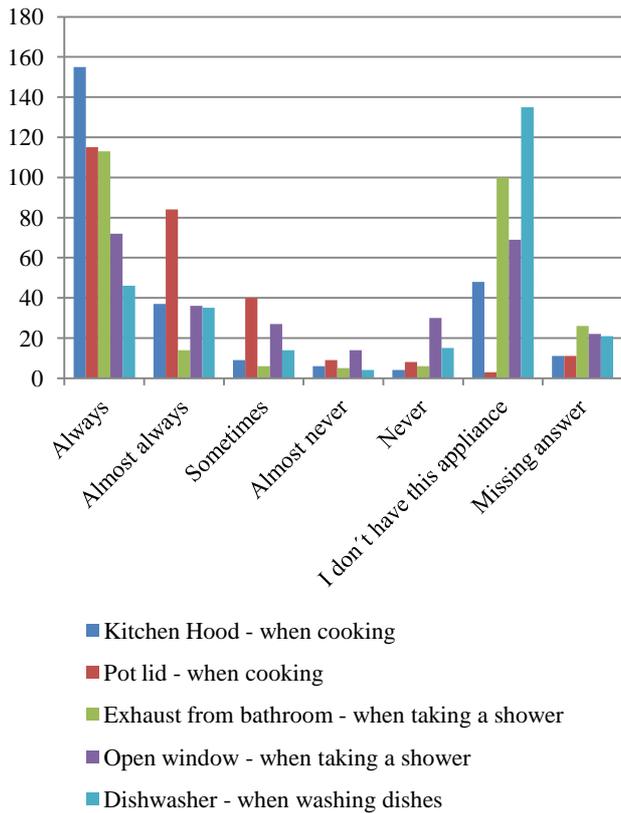- ■ Dishwasher - when washing dishes

Figure 7. Responses to the question "how often do you use the following appliances"

Figure 7 shows that most of the respondents use the appliances that are considered to save energy or eliminate the risk of moisture-related damage, always or almost always when required. On the other hand, 18% of respondents did not have a kitchen hood installed and 37% did not have exhaust from bathroom.

Another moisture source in the living space could be drying laundry. Here the situation varies between seasons. 90% of respondents dry their laundry outdoors in summer, while 30% dry laundry inside the living space in wintertime.

3.3 Energy

In response to the question "Imagine that you get the donation of 200.000 DKK (26.500 €) to improve your dwelling, what would you buy" respondents had to choose from 10 options where 4 were related to energy savings (new ventilation system, new solar panels, new windows, or new roof), five to home equipment such as new kitchen, new bathroom, new furniture, Hi-Fi. Respondents living in houses would mainly select energy saving appliances whereas respondents from apartments would much rather invest in new kitchens, bathrooms or furniture.

Figure 8 shows the difference in electricity bills in houses and apartments. As the average price was 2,5 DKK/kWh (0,33 €) in apartments most people use 100-400 kWh/month (mean = 250 kWh/month) whereas in houses they use 200-500 kWh/month (mean = 350 kWh/month). The overall average electricity consumption was 4200 kWh/household per year which was 22% higher than the average consumption in Denmark at that time.
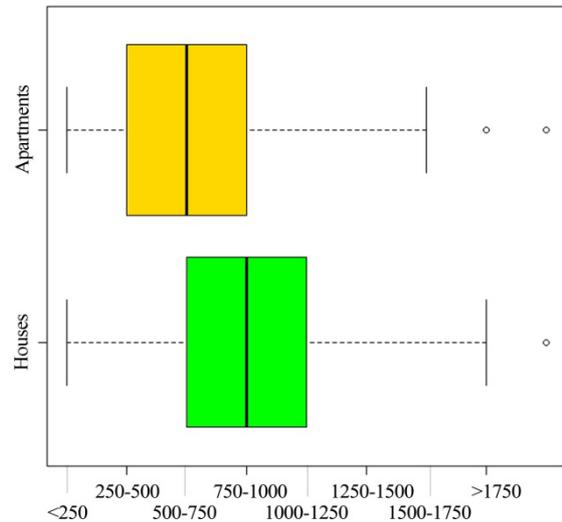

Figure 8. Electricity bills for apartments vs. Dwellings

Figure 9 shows the electricity bills for various numbers of rooms. As expected, electricity consumption increases with the number of rooms (Spearman's correlation coefficient 0.335, p-value <0,001), but it may be seen that there was quite large variation between dwellings with the same number of rooms. This variation reached 700%, and even the interquartile range was 200%.
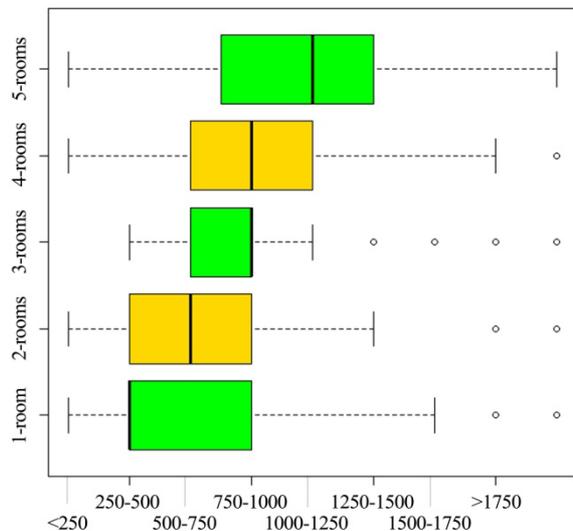

Figure 9. Electricity bills vs. number of rooms

4. Discussion

4.1 IAQ

A large number of respondents reported cold discomfort in winter (cold draft, too cold in the living space, cold floor). It has been shown that people living in privately owned houses complain less about having these problems than people living in apartments. This may be because it is easier to regulate the heating system in houses than in apartments, but is more likely to be due to increased tolerance of discomfort when the alternative is an increased cost of heating. Heating costs increase for tenants as well, but only as a group, so

individuals may feel that their neighbours will bear most of the increased costs. As condensation on windows was reported more often in apartments than in houses, it seems likely that house owners were keeping temperatures down to minimise heating costs.

The most common ventilation system consists of mechanical exhaust from the bathroom and the kitchen hood on the exhaust side and openings in the façade walls on the supply side. In this sample there were many dwellings without a kitchen hood and many without exhaust from the bathroom. The lack of kitchen hoods has a significant effect on the sick building syndrome.

It has been shown that occupants care more about their health than about costs when they open their windows or set the indoor temperature. This, together with the fact that the ventilation systems are inadequate, results in a quite high frequency of window opening (even in winter) in order to achieve proper ventilation. The negative effects of this behaviour are cold discomfort (draft, too cold in the living space) and high heat losses.

It is therefore hardly surprising that it is very important for the occupants to be able to open windows. Obtaining fresh air without a cold draft or uncomfortably low indoor temperatures is also of high interest to the respondents since these problems are currently very common.

Reports of high indoor temperatures in summer may also be due to low ventilation rates. Outdoor air temperatures in Greenland rarely rise above 20°C, so sufficient ventilation would easily balance high solar gains.

4.2　Habits

The high proportion of people who smoke inside the living space is surprising, as is the fact that the presence of children in the household does not affect whether the occupants smoke or not. It seems likely that smoking frequency will decline in the future, although the current trend is for it to increase in less developed countries, but in the meantime ventilation systems in dwellings in Greenland should be designed so that they make possible an increase in ventilation rates for short periods of time (when people are smoking). If used, this would speed up the removal of pollutants originating from smoking and from other sources such as burning candles and cooking.

Drying laundry inside the living space is a still widespread habit in Greenland. In order to decrease the risk of moisture damage, clothes driers venting outdoors should be considered as a solution. Increased ventilation rates would also help to decrease this risk.

4.3　Energy

The 22% higher electricity consumption in dwellings compared to Denmark is caused partly by less daylight in winter, but also by irresponsible lighting behaviour. Big freezers placed in the warm living space are quite common. Beside the fact that their compressors generate noise, their efficiency when placed in the heated space is decreased which also contributes to higher electricity consumption.

Heat consumption was excluded from the questionnaire because two different heating systems are in use. Apartments are mainly part of a district heating scheme while houses have individual oil furnaces. In apartments the tenants pay their share of the total heating cost, whereas in houses the owners pay for their own oil consumption, and here the bills are often not available. However, according to available statistics the average heat consumption is over 370 kWh/year per m^2. An obvious cause of such high consumption is that the building stock is poorly insulated and mainly ventilated by windows opening, in combination with the harsh climate. However, the complete lack of motivation for energy conservation that is apparent in this survey must play a large role.

However, efforts to decrease the energy consumption by introducing individual billing would have serious negative consequences. Inhabitants would most probably stop opening the windows, which would make the indoor environment even worse than it is and might adversely affect the health of the occupants. More allergies, asthma, headaches, eczema or dizziness could be possible consequences.

In order to avoid health problems, increase the quality of the indoor environment and decrease energy consumption, a series of measures should be taken.

Ventilation systems with efficient heat recovery should be introduced in all new buildings and should also be part of the renovation process for old building stock. The air supplied to the space must be at a temperature that is high enough to avoid draft problems. Occupants should preferably have an opportunity to adjust the air flow (within certain limits) in order to be able to match their actual demands at different times. Floor heating in newly built houses should be considered in order to avoid unpleasantly cold floors. Individual energy meters can then be installed to increase the motivation to conserve energy.

5.　Conclusion

There is obviously room for improvement in energy conservation and IAQ in Greenlandic dwellings.

Mechanical ventilation with heat recovery should be introduced in new and renovated buildings If possible, a certain degree of user control should be allowed.

The overall indoor climate as perceived by the occupants does not appear to be very poor; however its actual state still has to be determined by physical measurements.

In general, this study must be followed up to provide a complete overview of the current building stock if not is to be possible to improve living standards and energy conservation in Greenland.

References

Andersen, R.V., Toftum, J., Andersen, K.K. & Olesen, B.W. 2009, "Survey of occupant behaviour and control of indoor environment in Danish dwellings RID C-1925-2009", Energy and Buildings, vol. 41, no. 1, pp. 11-16.

Bjarlov, S.P. & Vladykova, P. 2011, "The potential and need for energy saving in standard family detached and semi-detached wooden houses in arctic Greenland", Building and Environment, vol. 46, no. 8, pp. 1525-1536.

Ihaka, R. & Gentleman, R. 1996, "R: A language for data analysis and graphics", Journal of Computational & Graphical Statistics, vol. 5, no. 3.

Johnson, R.A., Miller, I. & Freund, J.E. 2000, Miller and Freund's Probability and statistics for engineers, 6th edn, Prentice Hall, Upper Saddle River, N.J.

MORRIS, J. & GARDNER, M. 1988, "Calculating Confidence-Intervals for Relative Risks (Odds Ratios) and Standardized Ratios and Rates", British medical journal, vol. 296, no. 6632, pp. 1313-1316.

SELIGMAN, C., DARLEY, J. & BECKER, L. 1978, "Behavioral Approaches to Residential Energy-Conservation", Energy and Buildings, vol. 1, no. 3, pp. 325-337.

Statistics Greenland 2011, 14.11.2011-last update, Grønlands energiforbrug. Available: http://www.stat.gl/dialog/main.asp?lang=da&version=2009 01&link=EN&subthemecode=p2&colcode=p [2011, 10.6.2011].