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Performance of the Low-energy House in Sisimiut

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SUMMARY
A low-energy house was built in Sisimiut, Greenland in 2004-05 and since its inauguration in April 2005, its performance and operation have been object of study for researchers and students. The house is characterised by a highly insulated building envelope, advanced windows and a ventilation system with heat recovery, which should cut the energy consumption of the building to only half of what in 2006 became the permissible value in the Greenlandic building code. In addition to this, the house is equipped with a solar collector that supplies heat to the domestic hot water system and delivers auxiliary heat to a room in the building.

The paper will briefly introduce the design and technology of the house before reporting on the performance results until date. It has been a challenge in some aspects to introduce new technologies which have not been commonly used before in an Arctic environment, and the paper will illustrate some of the experiences in this regard.

KEYWORDS
Low-energy house, Arctic climate, design, measurements

INTRODUCTION
The objective of the low-energy house project in Sisimiut was to build a house with so little energy consumption that it could be justified to call it a low-energy house – given the conditions of the Arctic location. The definition of a low-energy house is that it is a house which consumes only half the energy permitted in the building code. The building code of Greenland from 2006 permits annual energy consumption for heating and ventilation of 230 kWh/m^2 for a single storey dwelling located north of the Arctic Circle. Given that this house has a ventilation system with heat recovery unit, it could be expected to consume around 70 kWh/m^2 less heating energy, and thus the, the permissible energy should be only 160 kWh/m^2, although there is official specification like this in the building code, since it does not assume dwellings to be equipped with a ventilation system with heat recovery unit. As a low energy house, it was set as a target that the energy consumption for heating and ventilation should be only half of that of the building code, and consequently the ambitious target value of 80 kWh/m^2 was chosen.

The means to reduce the energy consumption in comparison with common Greenlandic houses has been to use extra insulation in floors, exterior walls and the roof. A solar collector is installed on the roof to heat water for domestic use. The ventilation system is supplied with a heat exchanger that uses the warm exhaust air to heat the cold inlet air. Furthermore, improved windows are installed with low energy glazing using normally 3 layers of glass.

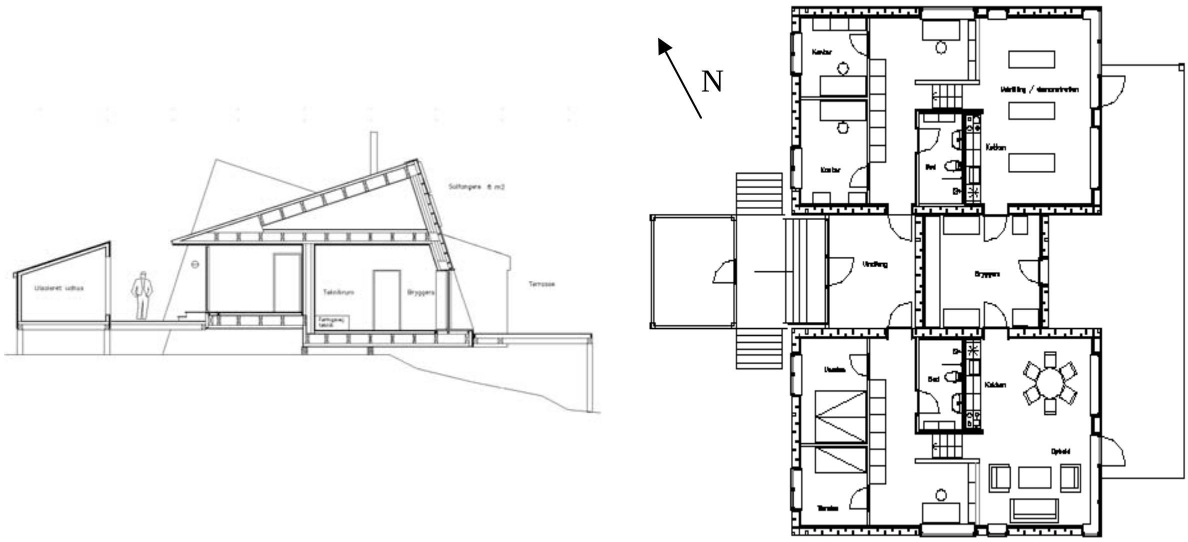

Figure 1. Cross section and floor plan of the low-energy house. The house is built as a double house with common scullery/boiler room and entrance hall.

THE LOW-ENERGY HOUSE

The low-energy house is made as a double-house with a floor area of 197 m², where the two living areas are built on each side of the boiler room and an entrance hall. Figure 1 shows a cross section and floor plan of the house. One of the two apartments serves as home for a family, while the other is used as an exhibition, and also occasionally functions as a guest house for visitors. Some descriptions of the building are given below, but more can be found in the proceedings of the inauguration symposium (Artek, 2005).

The building envelope

The building is generally made as a wood frame construction. The inhabited part is all in one floor, which is distributed over two slightly displaced levels, and there is a cold attic above the whole building, and an open crawl space below. The heat loss due to thermal transmittance of the building envelope constructions is kept at a minimum by using large insulation thicknesses and wooden posts and girders which come in two separate layers that don't touch each other, so thermal bridges are practically eliminated, see Table 1.

Table 1. Calculated U-values of the different constructions compared with the demands of the Greenland Building Code (GBC). The values include thermal bridge effects.

Construction	Insulation thickness [mm]	U-value calculated [W/m^{2}K]	U-value GBC 2006 [W/m^{2}K]
Floor	350	0.14	0.15
Walls	300	0.15	0.20
Roof	350	0.13	0.15

Windows

Three types of glazing units are used in the low-energy house: Type 1 is a 1+2 solution, made of one single glass with a hard low emission coating and a double low energy glazing unit. Type 2 is a combined double energy glazing and a vacuum glazing unit. Type 3 is a 2+1 solution made of one double energy glazing and one single glass with a hard low emission coating. Data for the glazing units are shown in Table 2. The net energy gain is calculated as a mean value of windows orientated north, east, west and south for a reference house.

Table 2. Heat transmission coefficient (U_g, U_w), solar energy transmission (g_g, g_w) and net annual energy gain (Q_g, Q_w). Index *g* for glazing and *w* for window.

Type	U_g W/(m²K)	g_g -	Q_g kWh/m²	U_w W/(m²K)	g_w -	Q_w kWh/m²
1: 1+2	0.7	0.45	172	1.0	0.30	-17.3
2: 2+Vac.glazing	0.7	0.40	136	1.1	0.27	-59.3
3: 2+1	0.8	0.56	228	1.1	0.47	67.1

Heating system

The low-energy house is constructed with a hydronic floor heating system based on PEX-tubes installed in aluminium plates just below the wooden floor boards. The floor heating system in the toilets is based on PEX-tubes cast in the concrete. The ventilation system is equipped with a heating coil which is positioned on the supply air stream after the heat exchanger. The heating coil is meant to ensure that the supply air is not delivered to the rooms at a too cold temperature. The ventilation system's heating coil is based on the same hydronic system as the floor heating.

Hot water for the floor heating and heating coil is supplied from an oil furnace, which is located in the boiler room of the house. Heat for the domestic hot water comes from a solar collector which has a size of 8 m^2 and faces south-east. The oil furnace supplies back up in periods when the solar heating is in insufficient. Finally, a radiator in the entrance hall is meant to be heated with excess heat from the solar collector system when available.

The ventilation system

A new heat recovery unit was developed for the low-energy house in Sisimiut in cooperation between EXHAUSTO A/S and the Technical University of Denmark. The dimensions of the unit are: Length 1,760 mm, width 930 mm and height 660 mm. The unit consists of two highly efficient aluminium counter flow heat exchangers coupled in a serial connection. A valve is able to switch the air flow direction through the units. When ice formation starts to reduce the airflow in the coldest exchanger the air flow direction is switched. The exchangers, valve and filters are mounted in a cabinet with 50 mm insulation, although the unit is recommended to be placed in a heated place to minimize risks of frost damages from the condensing water. The theoretical temperature efficiency of the heat recovery unit is approximately 90 %. A diagram of the system is shown in Figure 2.

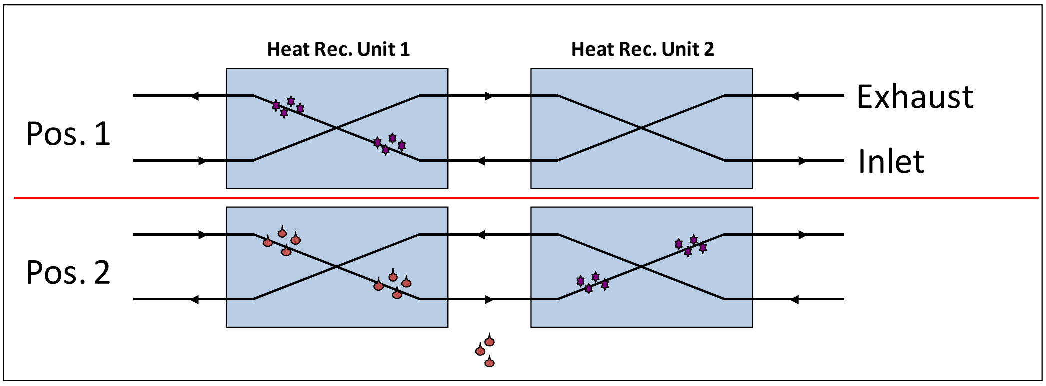

Figure 2. Diagram of the heat recovery unit with two heat exchangers.

The solar collector
The solar panels installed on the low-energy house are flat plate collectors. They have a total surface area of 8 m^2. The solar collector faces south-east and is tilted 70° from horizontal to have the optimal position in relation to the sun.

Energy balance
A calculation model has been set up in the thermal building analysis tool *BSim* (BSim 2009) to analyse the energy performance of the house. As the low-energy house is a double house made of two equal houses with common scullery/boiler room and entrance hall, the calculation model is simplified to only one of the two halves. Figure 3 shows the calculated contributions to the energy balance of the low-energy house. In the calculations, the heating set point temperature was 21 °C in all rooms except the two bathrooms where 23 °C were used. The assumed internal heat gain was 5 W/m^2 and the infiltration was 0.1 h^{-1}. The total ventilation rate was 45 l/s as required by the building code.

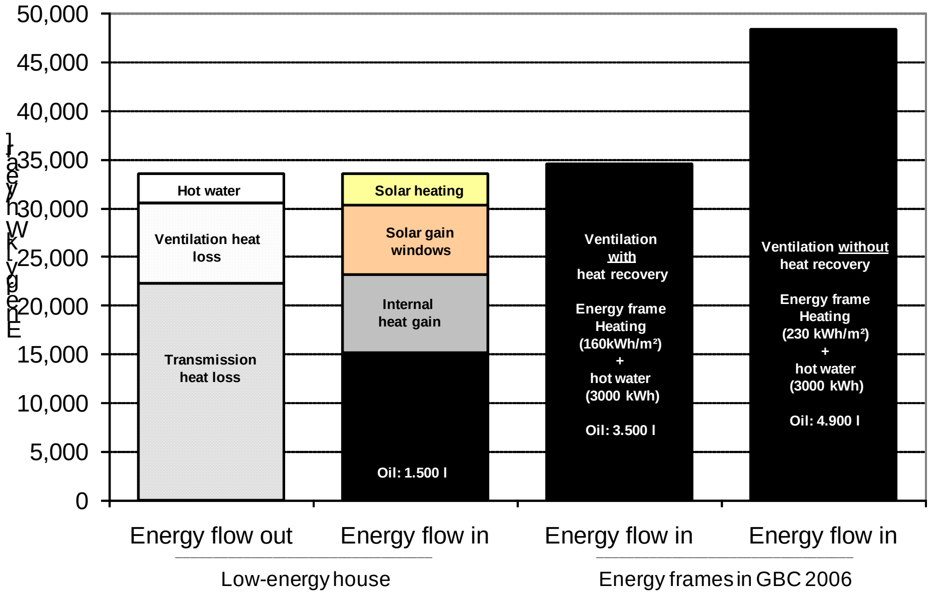

Figure 3. Energy balance of the 197 m^2 low-energy house compared with the demands of the Greenlandic building code.

The results are compared with the expected energy frame demands in the building code of Greenland. For a house with a mechanical ventilation system with or without heat recovery the energy frame demands are set to 160 and 230 kWh/m^2 respectively. It is seen that the energy consumption is simulated to be approximately 1,500 litres of oil per year. Compared with the energy frames of the building code it is seen that more than 3,000 litres of oil are saved every year. The simulation results show that the annual energy consumption of the low-energy house is below the target of 80 kWh/m^2 (Kragh et al., 2005).

MEASUREMENTS
There is a lot of measuring equipment built into the low-energy house. These are moisture sensors, energy meters for measuring the floor heating consumption, for measuring the solar collectors' energy production and the oil furnace's consumption. Measurements have been carried out since the house was inaugurated, and they are reported annually in periods that go from summer to summer.

The energy meters

The energy meters in the low-energy house are all accessible for on-line viewing on the following web-address: http://energyguard.dk/ using *Username*=dtu and *Password*=sisimiut.

Figure 4 shows the monthly energy consumption for heating (exclusive of domestic hot water), where year 1 is for the period July 2005 – June 2006. The house has not been inhabited during the period July 2007 – April 2008 during which period the house underwent some renovation activities: A separation wall was erected in the boiler room, and the wooden floor of the living rooms was changed because of a failure with the first delivered floor. The house was heated during the construction period, although in a somewhat unusual pattern.

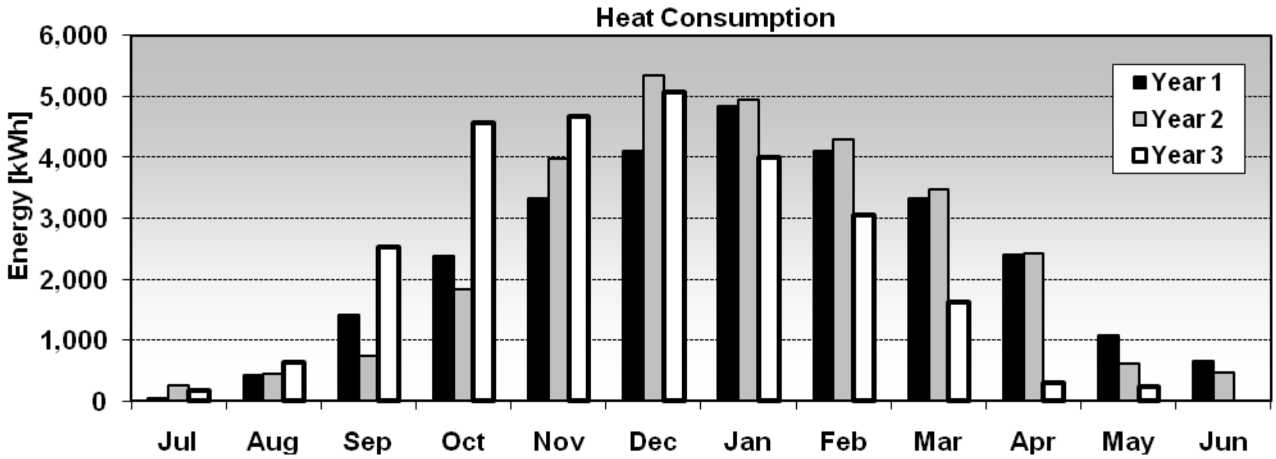

Figure 4. Heat consumption during the months of the first three full years of operation.

The total annual energy consumption for heating and for domestic hot water appears from Table 3. The table also explains how much energy comes from the solar heating system and from the oil furnace, and it lists the electricity consumption split up in household consumption for two apartments, and general electricity consumption for operation of the building services.

Table 3. Annual energy consumption and supply

	Year 1	**Year 2**	**Year 3***	**Unit**
Heating	28,091	28,792	27,030	kWh
Domestic hot water	2690	2269	344	kWh
Solar energy	1670	1885	n/a	kWh
Oil consumption	2953	3033	3056	litre
Electricity, house systems	2332**	4957	5524	kWh
Electricity, apartment 1	1601**	3315	337	kWh
Electricity, apartment 2	443**	998	107	kWh
Indoor temperature	22.6	22.7***	24.5****	°C

* House not inhabited from July to March (incl.)

** Just the period January – June

*** The period July – November 2007

**** The period April 1 – August 16, 2008

DISCUSSION

The realized annual energy consumption for heating has been around 140 kWh/m^2 during all three years of operation. This energy consumption is considerably above the targeted 80 kWh/m^2. Explanations for this discrepancy have been sought, and the following identified:

Higher indoor temperature than designed

The average indoor air temperature has been some 2.5-3.0°C higher than anticipated in the simulations for the design of the building. Revised simulations (Rode et al., 2007) show that this means an increase in the expected annual energy consumption from 80 kWh/m^2 to 92 kWh/m^2 (for indoor room temperature = 23°C).

Insufficient function of the heat recovery system

The heat recovery system has in some periods been blocked by ice. Beginning ice formation in the system has had the effect to impair the cyclic change of the order of the two parts of the heat recovery system, so the defrosting function has not been fully functional, and the frosting situation has gotten worse. In October 2006, an insulated box was built around the heat exchanger unit, and an electric heater ensured heating of the air around the box to a temperature that approaches normal indoor air temperature. However this initiative has not eliminated the problem, and the temperature efficiency of the heat exchanger remains around 50% (in some periods only 30%), while the system was expected to have an efficiency of 80% (Rode et al., 2007 and 2008). Wasted energy by insufficient heat recovery (estimate): 30% of ventilation heat loss = approximately 25 kWh/m^2.

Insufficient insulation of air ducts in attic

The exhaust air from the rooms has to travel some 20 m in the cold attic before it reaches the heat exchanger unit. The ventilation duct is insulated with 50 mm insulation, and a temperature drop of 5 °C has been measured before the air reaches the heat exchanger (Rode et al., 2008). The heat loss in the return air duct may further be a part of the explanation why ice has formed so easily in the heat exchanger. Also the air in the supply air duct has a similar temperature drop before reaching the diffuser at the room inlet. A plan to add more insulation to the exhaust and supply air ducts in the attic has still not been implemented at the time of writing this paper. The total annual heat loss from ducts and other air-handling units in the attic amount to some 5000 kWh, corresponding to 25 kWh/m^2. Some of this could be saved by insulating the ducts and units better.

Poor control of the heating coil for heating of the of the ventilation supply air

In order to prevent supplying too cold air to the rooms, the ventilation system has been equipped with an auxiliary heating coil on the line of the supply duct between the heat exchanger and the inlet to the rooms. However, the control of the heating coil has been malfunctioning, so hot air was often led to the rooms even in periods when no heating was needed. This has caused some extra heat expenses. Contradictory to the expectations, almost as much heat is consumed by the auxiliary heating coil as by the floor heating system of the house. Of the total heating energy consumed in the house (approximately 140 kWh/m^2), around 30-50 % have gone to the heating coil in the supply air duct (and the rest to the floor heating). Since the heat delivered to the auxiliary heating coil has been poorly controlled, and therefore not always needed, it gives an indication of how much heat has been wasted due to the malfunctioning control. It might be 10-20% of the 140 kWh, i.e. around 20 kWh/m^2.

User behaviour

In periods it does get quite warm in the house. A typical user reaction has been to open the terrace door in the living room to the outside in order to cool the air. However, even if the room air is warm, the outdoor air is always colder than the indoor comfort temperature, and this cold air will then be sweeping over the floor and the floor heating system.

Furthermore, it has been noted that the inhabitants, who in periods were occupying some parts of both apartments, quite often let the doors open between the living zones and the entrance hall, thereby causing an extra heat loss from the living zones.

Poor air-tightness of the building envelope

A so-called blower door test has been carried out on February 7, 2009. The test showed an average leakage of 3.2 h^{-1} measured at 50 Pa over- and under-pressure. While this air leakage is not too high compared to the Greenlandic Building Code, since there are no requirements, it is significantly above the requirement imposed since 2006 in the Danish Building Code, that the air change must not exceed 1.5 h^{-1} when measured at 50 Pa pressure difference. Problem areas were identified around windows, at floor joints, at electrical outlets, and possibly under the floor (see Figure 5).

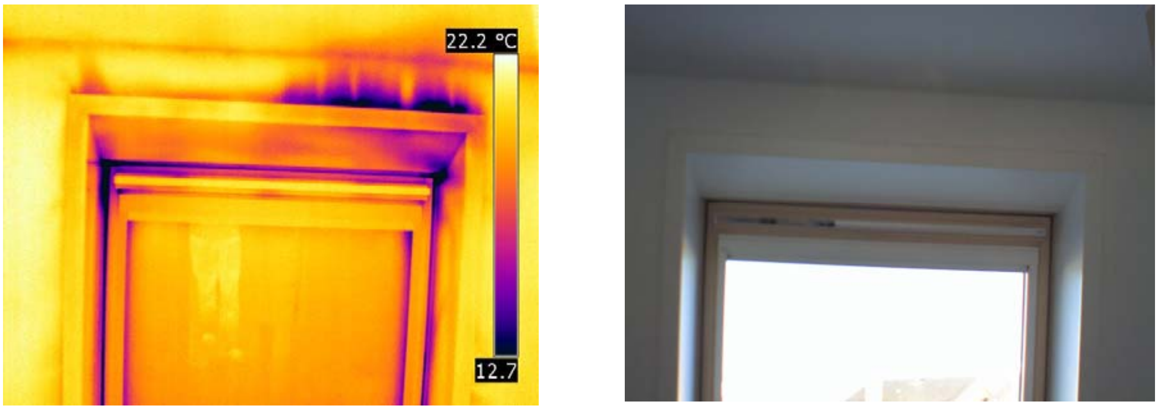

Figure 5. Infrared and normal picture of north-west facing window taken during blower door test.

For a building which is not in a sheltered environment, it can be expected that the free air change due to infiltration/exfiltration, n_{inf} is around 10% of n_{50} (DIN, 2003) and thus infiltration/exfiltration in the house can be expected to be around 0.32 h^{-1}. The volume of air in the building is 530 m^3, and thus the annual ventilation heat loss associated with this air change can be estimated to be 68 kWh/m^2 (based on the average outdoor temperature: -3.9°C). The assumption when designing the house was that the infiltration/exfiltration air flow would be only 0.1 h^{-1}, and thus the annual extra energy consumption due to poor air tightness of the building envelope, amounts to approximately 45 kWh/m^2.

Measurement of air change rate under neutral air pressure conditions were carried out using tracer gas equipment at three occasions in July 2005 (Mouritsen, 2006). The ventilation system was switched off, but its openings were not sealed from the rest of the house while the air change measurements were carried out. Mouritsen found air change rates of 0.39 h^{-1}, 0.27 h^{-1}, and 0.30 h^{-1}, i.e. values that support those found by the recent pressure test.

Electricity consumption

The annual electricity consumption for running the building services of the whole building amounts to approximately 5000 kWh. The anticipated consumption for running known systems such as fans, heating of the insulated box around the heat recovery system, data acquisition equipment and UPS, and the solar heating system, amounts to 1700 kWh (Rode et al., 2007). Thus a consumption of 3300 kWh remains unaccounted for. A current suspicion at the time of writing this paper, suggests that electric antifreeze wires for the sewer system could be the reason for this consumption – an investigation to verify this suspicion is pending.

Solar collector system

The solar collectors system has generally performed close to expectations by delivering some 1,700 kWh/year. This covers approximately 57 % of the hot water consumption of the house. The house and its inhabitants use around 150 litres of hot water per day.

CONCLUSIONS

The investigated house is a good low energy house, since 140 kWh/m^2 is a rather low energy consumption compared to the new Greenlandic Building Code's requirements (230 kWh/m^2), even though it is somewhat above the target set for the house (80 kWh/m^2). Some problem areas have been identified (Table 4), and it should be possible to eliminate some or all of those problems. Some of the problems which have arisen in the house are partly aggravated by its location in Arctic climate, e.g. frost formation in the heat recovery unit. But some problems are also due to the hard possibilities for quality assurance and follow up. Still today, it is not always easy to test and implement improved solutions when problems are discovered.

Table 4. Estimates of possible energy improvements (kWh/m^2):

Current heat consumption	140
Possible saving by air tightening the house (estimate)	45
Possible saving by insulating the heat recovery unit (estimate)	25
Possible saving by mending the control of the supply air's heating coil (estimate)	20
Possible saving by insulating the ducts and units in the attic (estimate)	10
Possible saving by various other improvements, e.g. user behaviour (estimate)	10

The current heat consumption subtracted all the possible savings seem to make it possible to obtain a final energy consumption, which is less than 80 kWh/m^2. However, this may not be realistic since some of the measures for savings also influence on each other.

ACKNOWLEDGEMENT

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