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Preliminary Results of Thermal, Energy and Moisture Monitoring of Five Wall Systems

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ABSTRACT

Depending upon the choice of building system the whole wall performance may not be consistent. Five test buildings located at the Alternative Village on the University of Manitoba campus in Winnipeg are currently being monitored to evaluate wall behaviour in a northern prairie climate. The wall systems currently being investigated are concrete with external foam, polyurethane structural insulated panels, dense packed cellulose, and fibreglass batt insulation. The batt-insulated structure has been chosen to be the benchmark as it represents the dominant vernacular approach to residential construction in Winnipeg. The test buildings are 4.88 m x 4.88 m (16ft x 16 ft) square by 2.4 m (8ft) in height to the bottom chord of the truss roof. All buildings are identically oriented with respect to the cardinal compass directions. Each structure has the same floor and roof system with the walls being the only variable. This paper presents some preliminary results of a monitoring programme.

Keywords : building envelope, insulation, dense pack cellulose, building performance

INTRODUCTION

One of the challenges with various building envelopes is evaluating their performance. Typically, the thermal resistance or "R-value" of the insulating material in the wall assembly is often used as an indicator of wall performance. For example, RSI 3.51 (R20) fibreglass batts may be installed within the cavity of a nominal 2x6 dimensional lumber stud wall. Depending upon the spacing of the studs the so-called whole wall R-value may be as little as RSI 2.98 (R17) as a result of the area occupied by the studs that have less resistance to heat flow. One has only to walk through their local do-it-yourself building supply store to experience a wide range of advertising purporting various performance ratings. With this impetus, a research programme was established to investigate the whole building performance of various wall systems. At approximately 0.61 hectares (1-1/2acres), the Alternative Village is located on the west side of the University of Manitoba campus. It is the site of the test programme discussed in this paper (Fig.1).

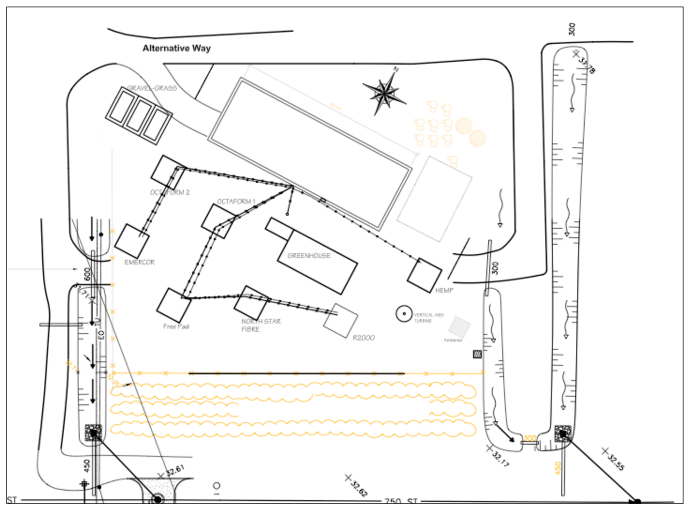


Fig.1. Test Site Layout

The origin of this research project grew out of relationships established between industry and the Alternative Village. Manufacturers or suppliers of wall and insulation systems were given an opportunity to evaluate their products in the prairie climate of Winnipeg. With design temperatures from -35°C to +30 °C, the site provides a wide range of conditions to evaluate their product (NRC, 2010). The test programme will run for a minimum of 12 months.

As of June 2011 there are a total of four building systems being studied with the fifth to come online in August 2011. The following is a summary of the building system types:

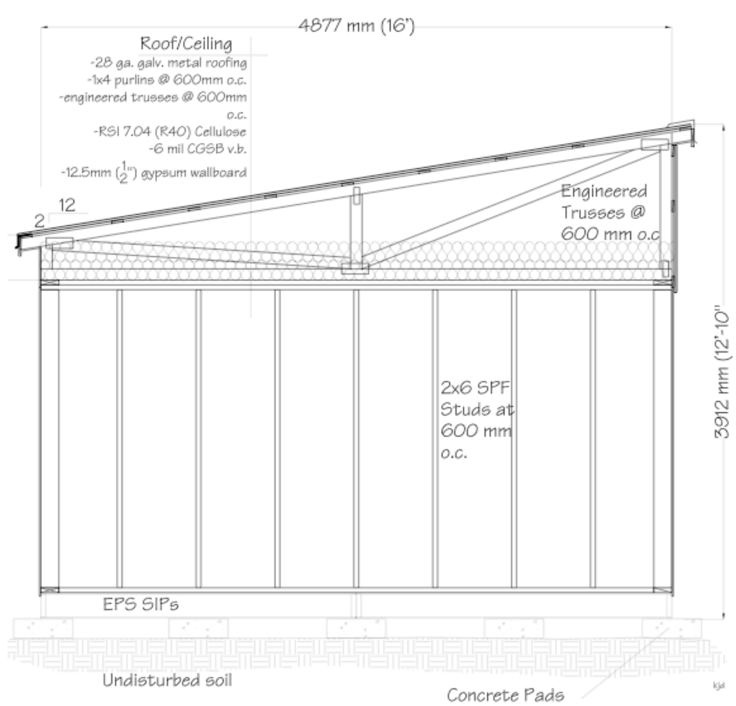
- The first is known as Octaform™, a combination of polyvinyl chloride (PVC) formwork with an exterior layer of 100 mm (4in.) of expanded polystyrene (EPS) foam. Concrete is poured into the PVC formwork and can range in thickness. The two structures on the site have 200 mm (8in.) and 100 mm (4in.) of concrete both with 100 mm (4in) of EPS foam insulation on the exterior.
- The second type of material is dense packed cellulose. The cellulose is blown in between the studs of a standard wood frame building to a prescribed density. The inner surface was covered with 6 mil CGSB vapour barrier on the interior face. The studs on the test building are nominal 2x6 SPF at a spacing of 600mm (24") on centre. The outer face of the structure was covered with 11 mm (7/16in.) OSB, with the inner surface being 12.5 mm (1/2in.) paper-covered gypsum wallboard. The inner wallboard is neither taped nor mudded.

- A third structure has been built of polyurethane structural insulated panels (SIPs). The wall thickness is a total of 114 mm (4.5in.) thick. It is comprised of 11 mm (7/16in.) oriented strand board (OSB) on each face with 76mm (3in.) of polyurethane foam.
- The fourth system is considered to be the baseline or benchmark structure to which all other buildings will be compared. It represents the “typical” wall system used for many tract-built homes in Winnipeg and elsewhere. The wall system is nominal 2x6 SPF studs at 600mm (24in) on centre. Fibreglass batt insulation was installed between the studs covered with 6 mil CGSB vapour barrier on the interior face. The outer face of the structure was covered 11 mm (7/16in.) OSB, with the inner surface being 12.5 mm (1/2in.) paper-covered gypsum wallboard. The inner wallboard is neither taped nor mudded.
- A fifth building type is currently under construction with monitoring to begin in August of 2011. The wall construction is 300 mm (12in.) hempcrete panels.

MATERIALS AND METHODS

One of the primary objectives of the research programme was to establish test buildings in which, as much as possible, the only variable was the wall system. All of the test buildings have a footprint of 4.88 m x 4.88 m (16'x16'). Figure 2 contains a cross section of a typical building. All of the test buildings have the same roof system comprised of galvanized metal roofing, 1x4 purlins, engineered trusses at 600 mm on centre, RSI 7.04 (R40) blown in cellulose, 6 mil CGSB vapour barrier and untapped 12.5 mm (1/2”) gypsum wall board screwed to the trusses. The floor system is comprised of SIPs using nominal 2x8 dimensional lumber, sheeted top and bottom with 11mm (7/16”) OSB with EPS foam inside. All of the buildings sit on beams and pads. Every building has only one access door at the mid distance along the north wall. There are no windows or other openings in the wall envelope at this time. All the buildings are oriented on the site with their walls corresponding to the cardinal points of the compass, adjusted for magnetic declination at Winnipeg.

Fig 2. Cross Section of Test Building



Each building has the following equipment installed for monitoring and heat.

- An Agilent 34972A LXI data switch with two 20-channel multiplexers is used for data acquisition and storage. This system is remotely accessible to allow for monitoring via the internet. This provides for data transfer without having to open the door. Also, this allows industry partners to see how their building is performing at any given time.
- T-type thermocouples have been installed within the wall system in each building. The number of thermocouples varies depending on the system. For the monolithic structures such as the Octaform, they are installed at mid-height and mid-length of the wall. A total of 19 locations are currently monitored in the Octaform and polyurethane SIP buildings. In the framed walls thermocouples have been installed midway between the studs and along the studs (Fig.3). This was done to compare the temperature profile to see if there is evidence of thermal bridging along the stud. A total of 26 locations are monitored on the framed buildings. Included in these locations are interior and exterior ambient temperatures. Readings are taken every 30 minutes.

Fig.3. Thermocouples on Stud

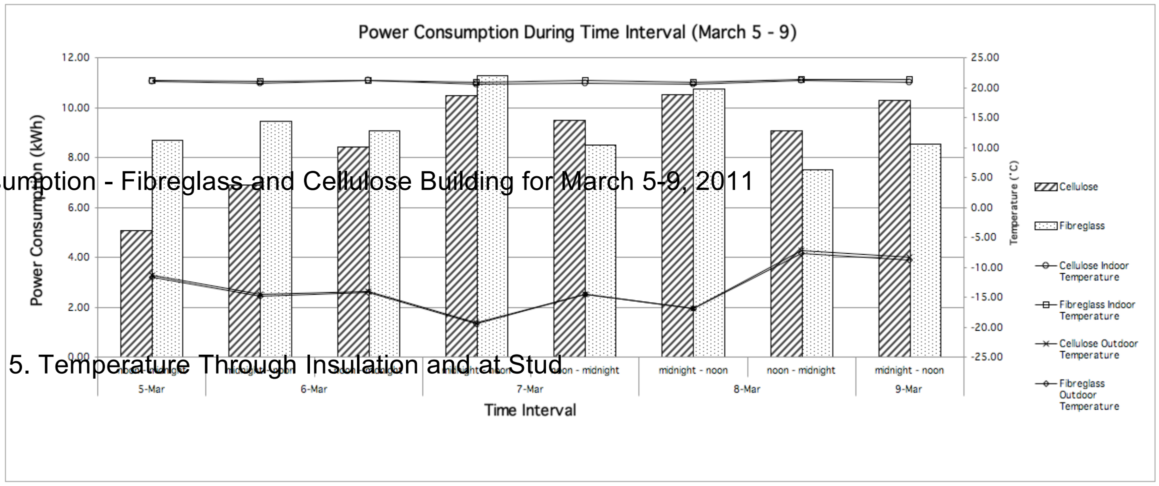
- Each structure has an Onset Hobo U12-011 data logger to monitor indoor temperature and relative humidity.
- Heat is provided by means of a 2000-watt electric baseboard heater. The power consumption is currently determined using Onset Hobo U9-004 motor on-off data logger combined with the actual wattage output of each heater. The indoor temperature is controlled with an analog thermostat.
- The weather conditions at the Village are monitored with two anemometers at 6 and 10 metres above local grade respectively. A pyranometer is used to measure solar irradiation.

RESULTS AND DISCUSSION

The research programme is scheduled to run for at least one year. Setup of the monitoring systems and commissioning was substantially completed in March of 2011. At this time preliminary data has been obtained from the buildings and analysis has been conducted to observe trends. For the purposes of this paper a snapshot has been presented to illustrate a comparison with the benchmark fibreglass building.

Figure 4 contains a comparison of the power consumption for the fibreglass batt and dense-pack cellulose buildings. It can be seen from the data that with the exception of March 9th, the power consumption for the cellulose building was less than the fibreglass building. Given that the framing system is the same for both buildings, these results appear to indicate that the dense-pack cellulose has a greater thermal resistance. The total power consumed over this five-day period was 73.75 kWh for the fibreglass compared to 70.17 kWh for the cellulose, representing about a 5% difference.

5a.

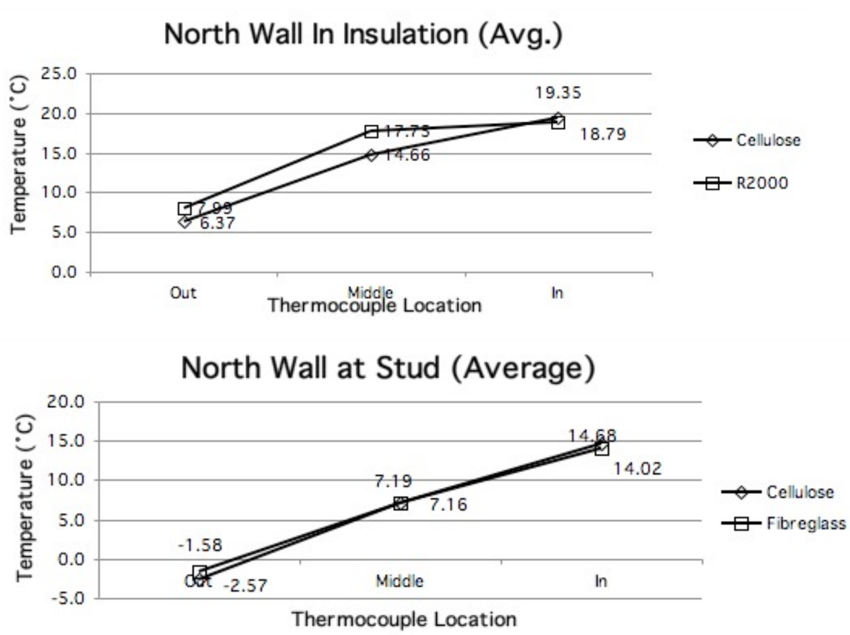


.4. Power Consumption - Fibreglass and Cellulose Building for March 5-9, 2011

5b.

Fig. 5. Temperature Through Insulation and at Stud

The interface between the insulating material and the stud face can affect performance. The temperature profile for the fibreglass batts and blown-in cellulose is shown in Figure 5 for the north wall. The behaviour of the insulation is similar in both cases. There is a slightly higher temperature at the midpoint of the fibreglass, while the trend is closer for both materials. Based on these results it appears that the fibreglass batts were installed



appropriately at the stud in this location. Often batt insulation is compressed more at the stud location during installation. It had been hypothesized that there would be a greater difference between these systems. The effect of framing members on the whole wall R-value is evident however. The temperature through the wall at the stud is more than 5°C lower than through the insulation.

Figure 6 illustrates the relationship between the Octaform 8 building and the baseline fibreglass building. The Octaform 8 wall system has 200 mm (8in.) poured concrete on the inside with 100mm (4in) of EPS foam on the exterior face. This is all encased in a PVC form system.

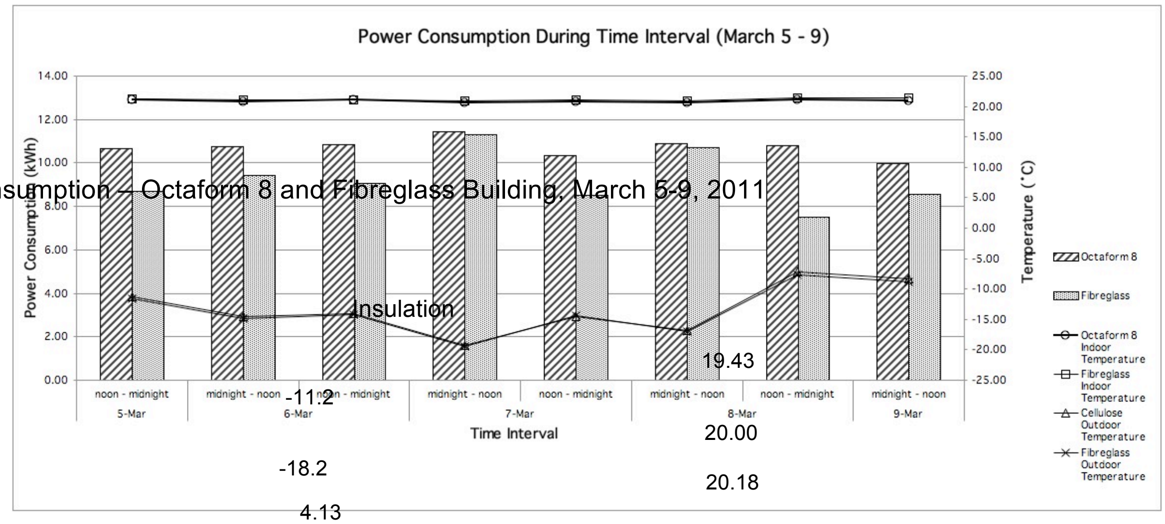
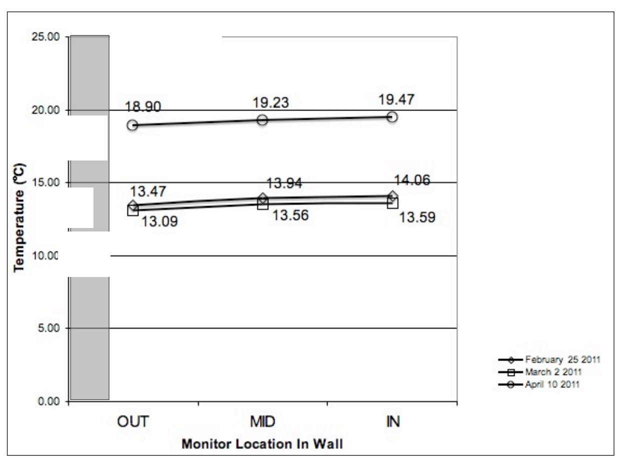
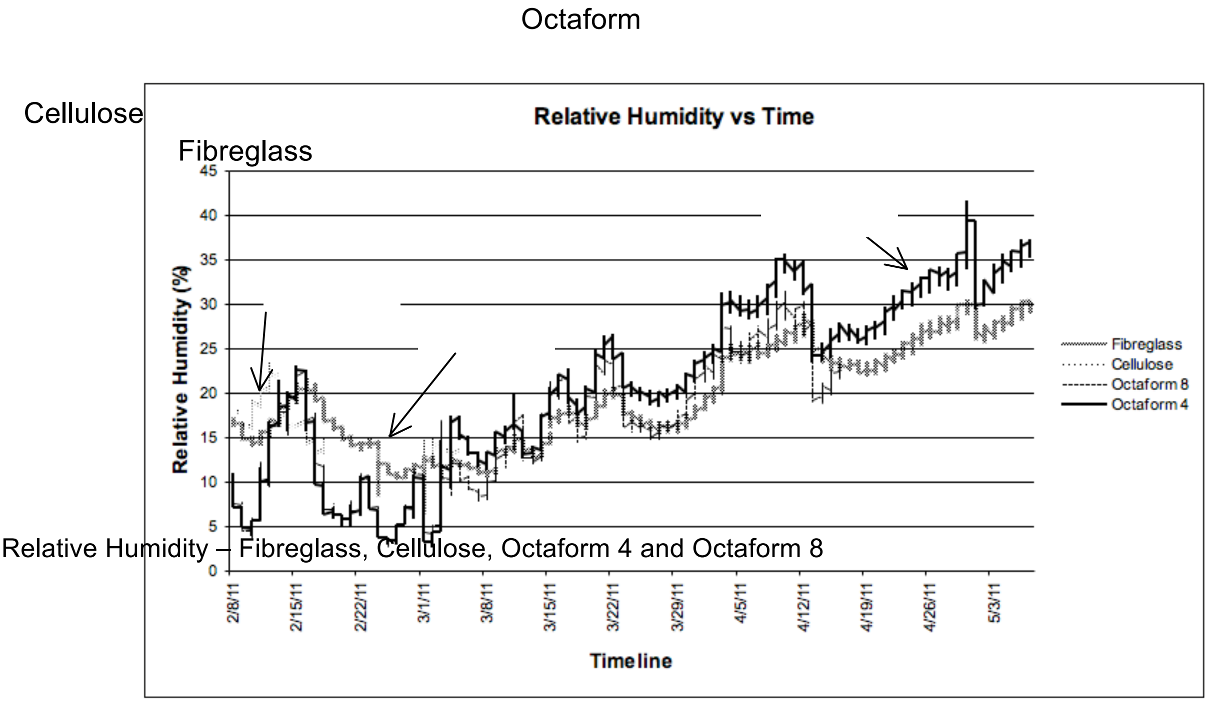


Fig. 6. Power Consumption – Octaform 8 and Fibreglass Building, March 5-9, 2011

Over the time period shown in Figure 6 the total power consumption was 73.75 kWh for the fibreglass and 85.72 kWh for the Octaform 8. This represents approximately a 16% difference. The relative R-value was determined for the two structures. Using a 12.5% framing component and including the exterior OSB sheathing the whole wall value for the fibreglass was found to be RSI 3.32 (R18.9). The RSI value for the Octaform 8 based on 200 mm of concrete and 100 mm of EPS was determined to be RSI 2.93 (R16.64). There is 12% less thermal resistance in the Octaform 8 compared to fibreglass that may account for some of the power consumption. Figure 7 shows the temperature through the Octaform 8 wall at three discrete times. The temperature gradient through the wall varies at most by only 0.6°C. The effect of the concrete mass is evident in the stable temperature through the wall.

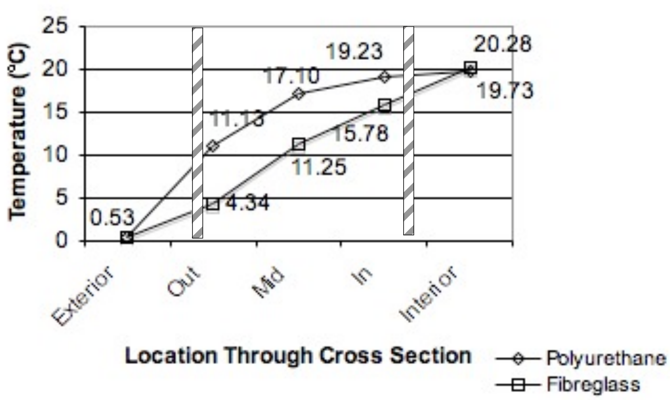
Fig. 7. Temperature Through Octaform 8





8. Relative Humidity – Fibreglass, Cellulose, Octaform 4 and Octaform 8

The relative humidity (Rh) was monitored in the test buildings. Figure 8 contains the relative humidity trends for four of the buildings –fibreglass, cellulose, Octaform 4 (100mm concrete) and Octaform 8 (200 mm concrete). The Cctaform structures exhibited variable Rh for approximately the first month. By the beginning of March 2011 the Rh trends are similar in all buildings. The Octaform buildings tend to exhibit higher Rh values.



The temperature profile through the north-wall cross section of the fibreglass and polyurethane is shown in Figure 9. The vertical bars on the plot indicate the sheathing layer. The nominal fibreglass RSI is 3.32, while the polyurethane is RSI 4.04. This represents approximately 18% more thermal resistance in the polyurethane foam. This difference is evident in the temperature gradient shown in Fig.9.

ONGOING RESEARCH

The monitoring programme will continue until the summer of 2012 and represent the end of Phase 1. Aside from ongoing monitoring the following activities and monitoring will be a part of the programme in the upcoming year.

- All the data from the test buildings will be streamed live to the Alternative Village web site over the next few months. The intent is to provide access to members of the village to observe site conditions by looking at data and with an IP camera on site.
- Air conditioners will be installed in the door of the test structures for the summer. Power consumption will be monitored.
- Infrared (IR) camera images will be taken at various times over the winter. The thermocouple data will be used to calibrate the IR images.
- Rh sensors will be installed within the wall systems in the polyurethane SIPs, cellulose, fibreglass and hempcrete structures.
- During the winter the temperature will be allowed to drop in all buildings at the same time to observe the rate at which temperature drops within the structure and through the wall system. Heat will be restored to observe the time to reach the test ambient temperature.
- Once the Phase 1 testing is complete research on increased humidity levels will be studied to investigate the effect on relative R values. Heat flux sensors will be added to the buildings to more accurately measure heat flow through the walls.
- It is proposed to investigate the effect of different wall covering, for example rainscreen applications.
- After the completion of Phase 1 one of the buildings will be selected to have a green roof to investigate the effect of an extensive roof system

CONCLUSION

This paper has provided an overview of a research programme being conducted at the Alternative Village at the University of Manitoba. There are currently five structures being monitored for thermal, energy and relative humidity behaviour. These structures include- Octaform, blown-in cellulose, fibreglass batts, polyurethane SIP panels and hempcrete soon to be in place. Preliminary results have provided insight into the performance of these wall systems. Ongoing research will continue to monitor the wall systems with further studies that will focus on the impact of humidity on thermal resistance values and their performance with air conditioning.

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