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Field Survey of Hygrothermal Behaviour within Wall Assembly Derived from Rain Penetration and Ventilation Performance of Exterior System

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Abstract. *Rainwater and moisture control are key factors for maintaining the durability of wooden houses. Wall assemblies with sidings are installed on vented cavities to build durable wooden houses. Moisture condensation does not occur generally behind a vapor retarder in walls assembled with a vented cavity; however, it is reported that the condensation mechanism which occurs in the wall assembly due to the high humidity of the vented cavity by rain penetration in Japan, there are only a few studies that investigate hygrothermal behaviour considering effects such as rain penetration in the exterior system. To unravel the mechanism of internal condensation derived from rain penetration, lab-experiments and field measurements were conducted. In the lab experiments, rain penetration from siding joints were quantitated using a water spray test. In the field measurements, for the exterior finishes of the experimental house, the sidings were installed on three types of vented cavities. To verify hygrothermal behavior within the wall assembly, intermittent long-term rain penetration into the vented cavity was reproduced for the experimental house. The measurements confirmed that internal condensation occurs with low ventilation performance, when moisture retained in the vented cavity is released into the wall assembly. This phenomenon is caused when the surface temperature on the sidings is increased because of solar radiation after rain. In conclusion, rain penetration through exterior finishes has a significant effect on the moisture behavior of wall assemblies. The obtained results verify that moisture condensation at the vapor retarder was caused by several factors including rain penetration, insufficient ventilation, and solar radiation. To maintain durability, it is important to ensure a ventilation performance and not retain moisture.*

Keywords: *Concealed Condensation, Vented Cavity, Rain Penetration, Absorption and Desorption, Field Survey, Siding.*

1 Introduction

Rainwater and moisture control are key factors for maintaining the durability of wooden houses. Wall assemblies with claddings are installed on vented cavities to build durable wooden houses (Figure. 1). In Japan, a fiber reinforced cement siding (hereinafter, called siding) is provided as an exterior system for outer walls in several houses. In this system, a vented cavity is provided between the siding of the primary waterproof layer and a water resistive barrier sheet of the secondary waterproof layer; the rainwater from the siding joints and the moisture from inside the house are discharged quickly (Figure. 2).

Recent years have seen an increase in houses designed with low eaves that experience rain penetration through the sidings under heavy rain; thus, the risk of rain penetration is increasing. It is difficult to completely prevent rain penetration into a vented cavity (Sahal, Lacasse and

Kimura). Technical note of National Institute for Land and Infrastructure Management of Japan has reported moisture condensation and structural decay of the wall assembly caused by rain penetration and insufficient ventilation. It is suggested that the condensation mechanism which occurs in the wall assembly due to the high humidity of the vented cavity by rain penetration (Umeno, 2011). Rain penetration have been considered evaluation methods such as ASHRAE Standard 160 in North America. However, there are only a few studies that investigate hygrothermal behavior considering effects such as rain penetration in the exterior system in Japan.

To maintain durability of wooden houses with the exterior system, this study confirmed the quantity of rain penetration from the siding joints using a water spray test, measured the temperature, humidity, and moisture content within the wall assembly during intermittent rain penetration into the vented cavity in the field survey. These results were used to clarify the mechanism of moisture accumulation in the wall assembly. Furthermore, the vented cavities of different cases were compared, the verification data on the ventilation performance of each case were verified. The impact of rain penetration on the exterior system of the hygrothermal behavior within wall assemblies was discussed.

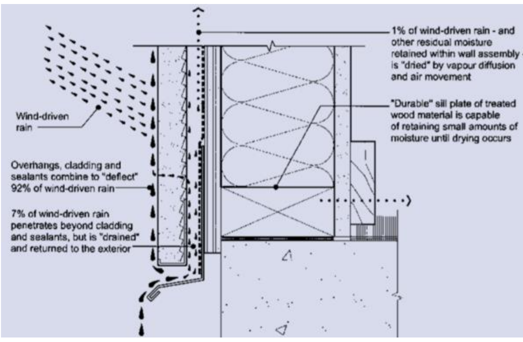

Figure 1. Four Line of Defense (Moisture Design for Wood-Frame Buildings, Canada).

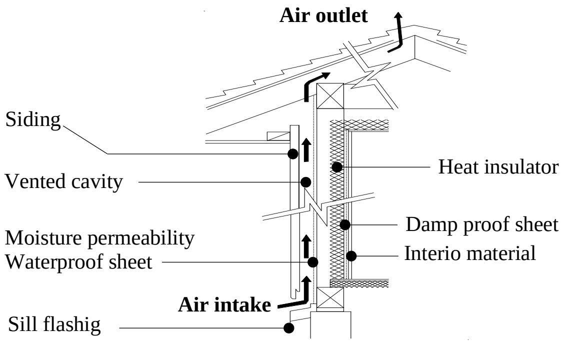

Figure 2. Siding standard installation method.

2 Quantification of Rain Penetration from the Siding Joints Using a Water Spray Test

To measure the quantity of rain penetration from the siding joints of an exterior system, the water spray test (JIS A 1517: Water tightness test under dynamic pressure) was performed.

As for the water penetration through the siding joint under strong wind, it is generally assumed that the rainwater flows over the shiplap joint and penetrates the vented cavity (Fig. 3(1)). When the wind is weak, the rainwater flows across the surface of the shiplap and penetrates into the vented cavity through the sealing area between the horizontal joints of sidings (Fig. 3(2)). The horizontal joint of the siding was placed at the center of the test specimen, and the quantity of rain penetration was measured with a plastic container. Figure 4 shows an outline of the experimental apparatus.

2.1 Experimental Conditions

General water spray tests are conducted under the conditions of high pressure difference (150–

350 Pa) and high water volume (4 l/min・m^2). However, frequency of these conditons are rare in real crimate data. To understand the quantity of rain penetration under the condition that may frequency occur in rainy day, this test was conducted at low pressure (0–250 Pa) and low water volume (0.2–0.8 l/min・m^2). The duration of the water spray test was 11 min; the pressure condition was not a pulsating pressure but a constant pressure.

To confirm the difference caused by the siding application method, test specimens were assembled using two application methods for a typical shiplap joint. Case A has a two-way shiplap with the top and the bottom; the left and right sides are joint using a sealant. Case B has a four-way shiplap with the top, bottom, left, and right. Figures 5 and 6 show the outline of specimen. In addition, the quantity of penetrated water and the water penetration rate in the water spray test were obtained from the following equation:

$$J_p = \frac{m_w}{t} \tag{1}$$

$$f = \frac{J_p}{R_w} \times 100 \tag{2}$$

where J_p is the quantity of penetration water (g/s), m_w is the measured total quantity of penetration water (g), t is the duration of the water spray test (s), f is the water penetration rate (%), and R_w is the quantity of water spray (g/s).

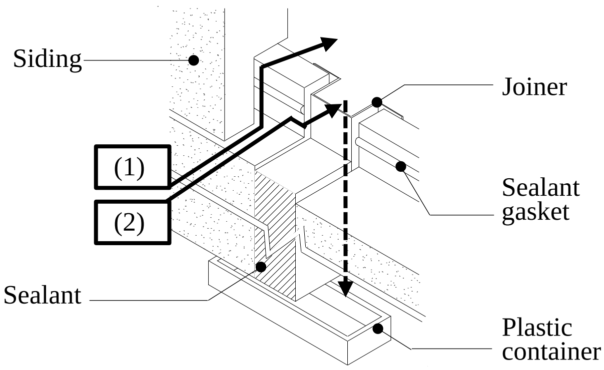

Figure 3. Water leakage path at two-way shiplap joint and Detail at the bottom of specimen.

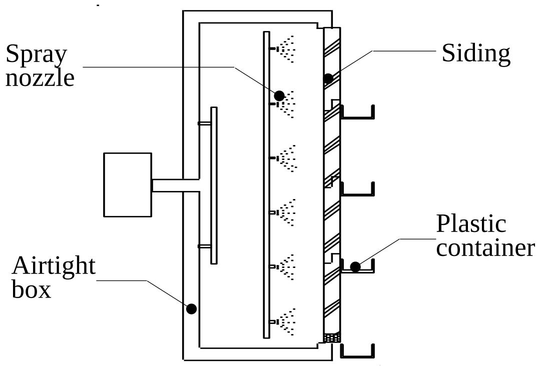

Figure 4. Apparatus for water spray test.

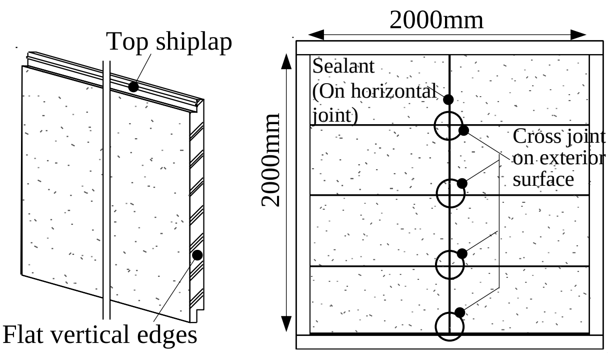

Figure 5. Siding shape of Two-way shiplap and Test specimen of Case A.

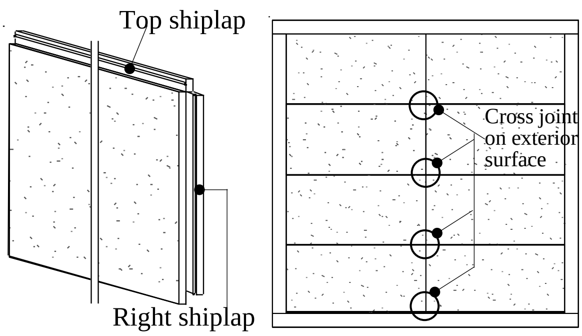

Figure 6. Siding shape of Four-way shiplap and Test specimen of Case B.

2.2 Relation Between Water Penetration Rate and Pressure Difference

Table 1 and Figure 7 show the experimental results. There are differences in the water penetration rate with the siding application.

For case A, under the conditions that rain penetration water was observed with a pressure difference of less than 150 Pa, the water that ran across the surface of the shiplap—the path shown in Fig. 3(2)—was transmitted to the sealant part of the horizontal joint, and it flowed down to the vented cavity. This water was accumulated in the plastic container at the bottom. When the pressure difference was 250 Pa, the water flowed over the sealant gasket of the shiplap joint shown in Fig. 3(1) and then flowed down the back of the siding. As a result, the water penetration rate increased significantly. For Case B, continuous flow occurred even in a pressure-equalized condition because there were pinholes at the cross joint on the exterior surface (Fig. 8). Thus, considerable penetration water that the water penetration rate was 5–11% was measured when the pressure difference was 0 Pa.

Owing to the difference in the siding application method, it is conceivable that there is no waterproofing performance criterion for driving rain. Furthermore, there is a possibility that the quantity of penetration water may increase because of the deterioration of sealants and the opening of the siding joint, which was caused by hardening shrinkage.

In consideration the above results, it is necessary for maintaining durability to consider the assumption that rainwater enters the vented cavity.

Table 1. Quantity of penetration water and water penetration rate.

Quantity of water spray (L/min・m²)	Pressure difference (Pa)	Case A			Case B		
		m_w (g)	Jp (g/s)	f (%)	m_w (g)	Jp (g/s)	f (%)
0.2	0	0	0.00	0.00	788	1.19	11.31
	15	0	0.00	0.00	812	1.23	11.65
	100	0	0.00	0.00	1177	1.78	16.90
	150	0	0.00	0.00	1497	2.27	21.49
	250	2245	3.40	32.22	2068	3.13	29.69
0.5	0	0	0.00	0.00	1200	1.82	6.91
	15	0	0.00	0.00	1408	2.13	8.11
	100	26	0.04	0.15	1941	2.94	11.18
	150	29	0.04	0.20	2472	3.74	14.23
	250	4805	7.28	27.67	3368	5.10	19.39
0.8	0	7	0.01	0.02	1385	2.10	4.80
	15	12	0.02	0.04	1594	2.42	5.52
	100	27	0.04	0.09	2197	3.33	7.61
	150	46	0.07	0.20	3082	4.67	10.67
	250	4859	7.36	16.83	4329	6.56	14.99

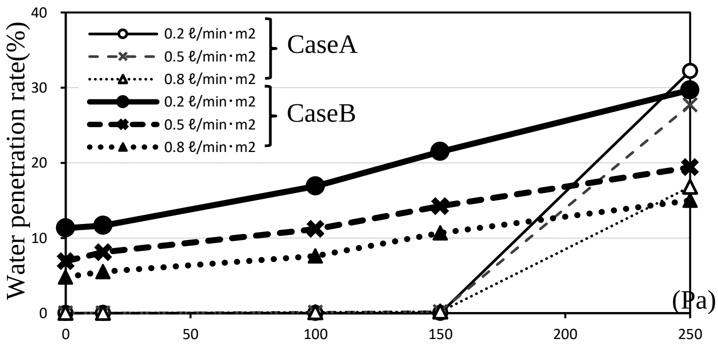

Figure 7. Relation between water penetration rate and pressure difference.

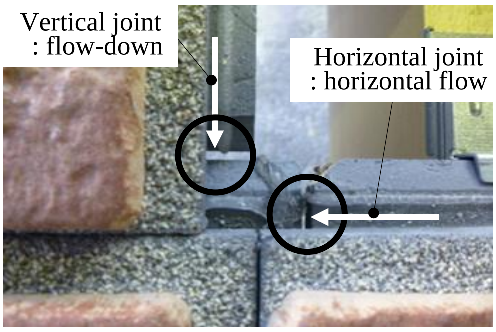

Figure 8. Leakage path (four-way shiplap joints).

3 Field Survey of Hygrothermal Behavior within Wall Assembly Derived from Rain Penetration

From the results in the previous section, it was suggested that wall assembly with a vented cavity using the siding has a risk of rain penetration from the shiplap joint. In this section, to unravel the mechanism behind internal condensation caused by moisture from the rainwater, an experimental house that reproduces intermittent long-term rain penetration into the vented cavity was constructed, and the hygrothermal behavior within the wall assembly was measured.

3.1 Outline of the Experimental House

The experimental house with a wood panel construction was constructed on the grounds of Ashikaga University in Tochigi (about 80km north of Tokyo). Three types of cavity configurations were installed in experimental house to compare the ventilation performance,

Figure 10 shows the configuration of cavity. Case (1) is a horizontal furring strip (cavity depth: 12 mm), case (2) is a panel clip (cavity depth: 6 mm), and case (3) is a panel clip (cavity depth: 15 mm), horizontal furring strips is insufficient ventilation, while panel clips secure a ventilation path. The cavities are at 910 mm intervals.

The bottom of the vented cavity is open with a sill flashing. The upper end of the vented cavity is open to the outside by ridge ventilation through the attic space (Fig. 2).

For the quantity of rain penetration into the vented cavity, the rainwater collected with a pouring funnel attached to the eaves was injected directly into the vented cavity from the center of the wall surface using a tube. The diameters of the funnel were selected to reproduce the intermittent long-term rain penetration in proportion to the precipitation. For Case (1), 80mm funnel size was installed in three places, and water injection was divided into three parts: upper, middle, and lower areas of the horizontal furring strips. For Case (2) and (3), three times size of the funnel was installed respectively.

3.2 Measurement Item

Figures 9 and 10 show the measurement items and measurement positions in the wall. The temperature, humidity, and moisture content were set near the center height of the first floor (FL + 1300 mm). The temperature and humidity were measured outside the insulation and inside the insulation; the moisture content was measured for the outer plywood facing the vented cavity. The measurement interval was 60 min, and the measurement period started from September 2018. Air conditioning in the room was not used.

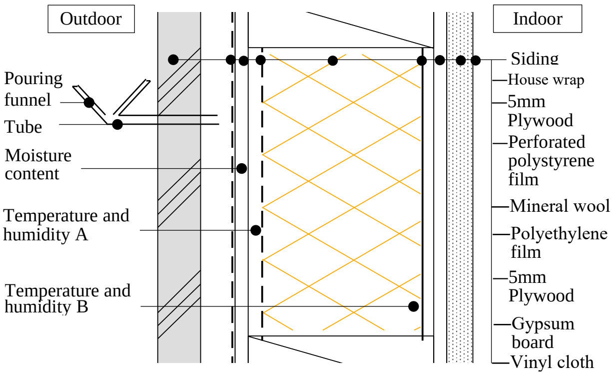

Figure 9. Wall configuration and sensor location.

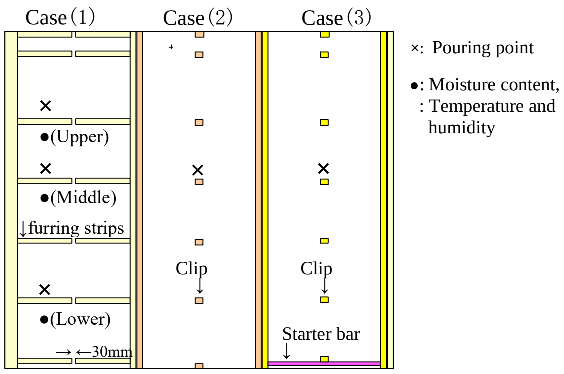

Figure 10. Configuration of cavity.

3.3 Results and Discussion

3.3.1 Increase in humidity and plywood moisture content due to rainfall in autumn

As an example of the measurement results in autumn, Fig. 11 shows the relative humidity between the insulation and vapor barrier. The outdoor temperature and precipitation are based on the weather data of the neighboring City. The relative humidity in the wall assembly increased after the rainy day, and moisture derived from rain penetration gradually accumulated in the wall due to repeating rainy and sunny days. Intermittent moisture condensation observed in some cases in early October.

The moisture in the wall assembly gradually decreased with reducing the quantity of precipitation since October 8. From this result, it can be indicated that rain penetration has a considerable impact on moisture accumulation in the wall assembly.

3.3.2 Process of hygrothermal behavior within wall assembly and the impact of ventilation performance.

Figures 12 and 13 show daily variations of relative humidity on the east side of wall on October 7, at location A (between outside plywood and perforated polystyrene film) and location B (between insulation and vapor barrier) were shown in Figure 9. Moisture condensation continues more than 9 hours at the location B with case (1) and (2), while it occurs less than 1 hour at the location A. In addition, relative humidity at location B increases with rising outdoor temperature.

From this result, it can be confirmed that moisture from rain penetration is accumulated on the indoor side. This phenomenon is thought to be the result that moisture retained in the sidings and the vented cavity was released by solar radiation; moisture that could not be discharged from the vented cavity moved to the wall assembly of the indoor side at a low temperature. Thus, temperature fluctuations due to solar radiation have a significant effect on hygrothermal behavior within a wall assembly. Temperature fluctuations release moisture retained in the building materials, which forms water vapor and move through wall assembly and materials. Consequently, the moisture condenses on the indoor side of the low-temperature part.

Compare the ventilation performance with different cavity configurations. The rain penetration water in case (1) with 12 mm of the cavity depth tends to accumulate within the wall assembly, because it generally remains at the horizontal furring strips. Furthermore, insufficient ventilation performance extended duration of moisture condensation to more than 12 hours at the location B. Although the remained water in the vented cavity of case (2) is less than case (1), duration of moisture condensation reached 9 hours because of less ventilation performance due to thin cavity depth. As for case (3) with the panel clip and 15 mm of cavity depth, the moisture condensation did not occur because adequate ventilation and drainage performance was secured.

From the above results, the impact of ventilation performance on hygrothermal behavior within the wall assembly was confirmed. As in case (3), adequate ventilation performance tends to reduce moisture accumulation in the wall assembly. To maintain durability, it is important to ensure a ventilation performance and not retain moisture within the vented cavity.

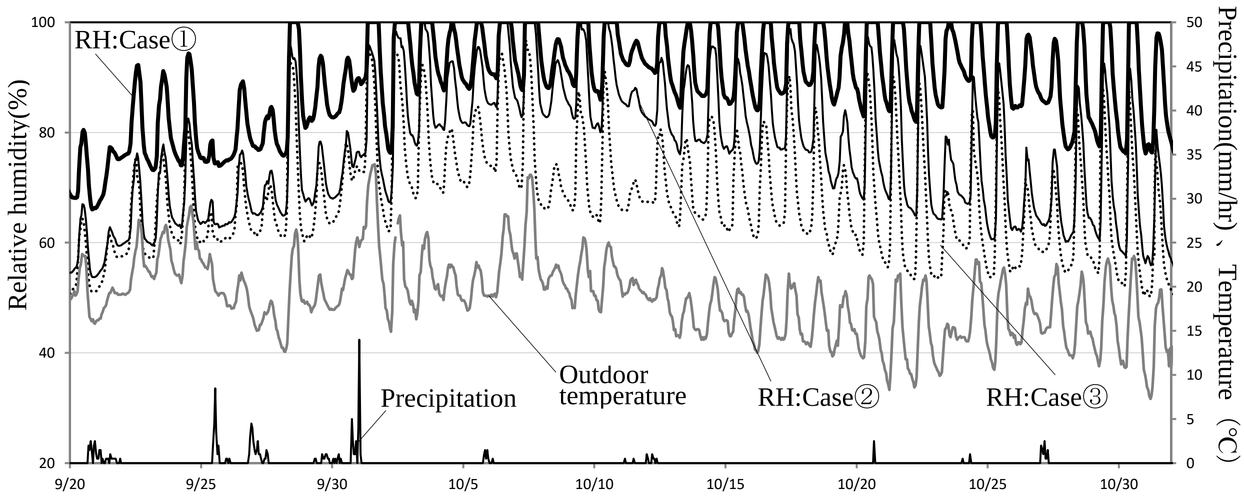

Figure 11. Relative humidity variation on the east wall location B.

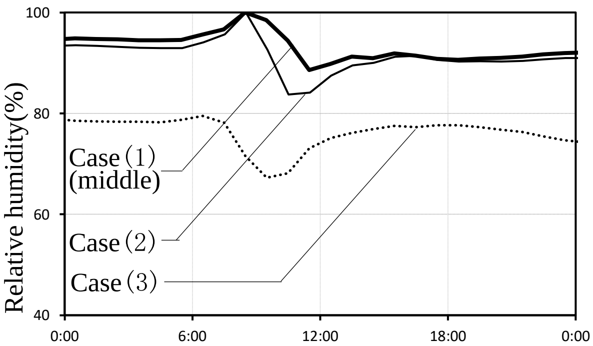

Figure 12. Relative humidity variation on east wall ocation A（10/7）.

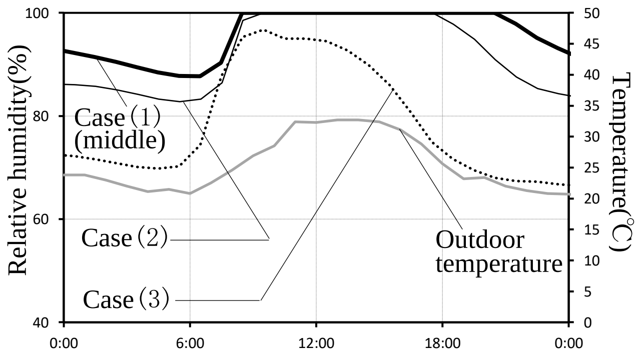

Figure 13. Relative humidity variation on east wall ocation B（10/7）.

4 Conclusion

This study was demonstrated the moisture accumulation in the wall assembly caused by rain penetration from the siding joints. In addition, the authors obtained an outline of the hygrothermal behavior within the wall assembly based on ventilation performance in the experimental house. The findings of the study are as follows:

- According to the quantity of rain penetration into the siding joints performing the water spray test, it was confirmed that there were significant differences in the water penetration rate between the application methods. For case B, continuous flow occurred even in a pressure-equalized condition because there were pinholes at the cross joint on the exterior surface. The rain penetration rate is 5–11% at low pressure difference (0–15 Pa) where the frequency is high. Thus, it is necessary for maintaining durability to consider the assumption that rainwater enters the vented cavity.
- According to the field survey of the experimental house, the relative humidity in the wall assembly increased after the rainy day, and moisture derived from rain penetration gradually accumulated in the wall. Intermittent moisture condensation observed in some cases. From this result, it can be indicated that rain penetration has a considerable impact on the moisture accumulation in the wall assembly.
- For the cases of low ventilation performance, the moisture condensation in the wall assembly observed more than for 9 hours in daytime. The case of high ventilation performance did not occur the moisture condensation. To maintain durability, it is important to ensure a good ventilation performance and not retain moisture.

Further studies are needed to develop a design method that can maintain the durability of wooden houses using the exterior system; in a future study, the authors expect to indicate the behavior of rain penetration water in the vented cavities and the ventilation characteristics.

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