WILL THE REAL R-VALUE PLEASE STAND UP

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ABSTRACT

This paper describes an approach to determine actual R-values in existing wood framed wall construction as compared to component calculated and prescribed R-values.

The study examined a recently remodeled 1913 residence in Portland, Oregon. Four exterior framed wall areas, at various locations, were examined and tested to determine their actual R-values. The results and analysis confirmed that the wall assemblies thermally underperformed as compared to the Oregon Dwelling Specialty Code and energy standard requirements for which they were based.

The study provides useful information for designers and contractors when assessing actual thermal wall performance and planning thermal improvements for existing residential construction.

1. INTRODUCTION

As designers and builders have you ever wondered if the R-values prescribed and installed in various construction assemblies actually perform as designed? Local and state building codes, and energy standards such as ASHRAE, provide specific performance requirements. Basic wall component calculations provide designers a prescriptive method to predict the overall R-values in order to comply with these building codes and standards. With major residential energy conservation improvements proposed in the government's new economic stimulus package, energy retrofitting of America's existing residential buildings will be a major priority in the very near future. This will require more accurate energy assessment tools for use by designers, contractors, and energy auditors. This study offers a method for determining the actual R-values of existing exterior wood framed walls.

The focus of the study was a home built in 1913 in Portland, Oregon. The home, a four-square bungalow, was recently renovated in 2004-2005 (Fig. 1). The two story structure, approximately 1900 square feet, has three bedrooms and 2-1/2 baths. It included a partial basement set five feet below grade. The wood framed structure has nominal 2x4 studs (balloon framing) in the original building section and 2x6 studs (platform framing) in the newer addition. Both cellulose and fiberglass insulation have been installed in the exterior walls.

The home was used as a case study to test the R-values of four wall locations within the structure. An infrared thermography camera at the exterior walls was used over the course of one evening to record interior and exterior surface and air temperatures. The camera also helped determine the location of framing members and to verify the condition of insulated wall cavities. The study was limited to simple wall areas, not including window or door openings. An R-value evaluation chart, provided by Infrared Training Center (ITC) and the National Comfort Institute, was used to interpret the results. (1)(2)

Fig. 1: *Southeast Elevation*

2. THE PROBLEM & HYPOTHESIS

Most existing residential single family homes have wood frame stud wall construction. A common method for increasing the energy efficiency of walls during renovations or energy conservation improvements is to mechanically apply or hand place insulation. The most often used insulation materials are blown-in cellulose, or batt and blanket fiberglass. While insulated cavities provide the bulk of the wall's thermal protection, framing constitute between 15-30% of the wall area and can reduce the whole wall effective R-value by thermal bridging. In addition, other factors such as poor installation methods and air infiltration can also affect the overall R-value. Because of these short-comings, whole wall R-values may not be reached as predicted or required.

This study demonstrates that because of the above factors, the original 2x4 framed exterior walls, insulated as prescribed to meet the minimum energy code R-15 value, do not achieve the R-value required by the 2003 Edition of the Oregon Dwelling Specialty Code for One and Two Family Dwellings.

3. METHODOLOGY & EQUIPMENT

The methodology used to provide estimated and actual R-value data includes five basic steps:

Step 1 - Select Wall Test Areas: Four original wall areas were tested (Fig. 2 - 5) to provide a minimum and diverse sample study size. All of these areas have actual 2x4 (two inch by four inch) stud construction. Three areas were insulated with mechanically blown-in cellulose, and the fourth area was hand applied fiberglass batt insulation (Fig. 4).

Fig. 2: *Second Floor Stair Landing East Wall-1*

Fig. 3: *Main Floor Lower Stair Landing East Wall-2*

Fig. 4: *Second Floor Bedroom South Wall-3*

Fig. 5: *Main Floor Dining Room West Wall-4*

Step 2 – Investigate As-Built Conditions: If possible, determine the existing as-built wall components and dimensions. This may require minor probing or invasive testing. This information is helpful in predicting R-values using the component calculation method, and especially for comparison purposes with the actual calculated R-value.

Step 3 - Record Thermal Images: Thermal image readings were taken at the four wall locations, both on the interior (Fig. 6) and exterior surfaces (Fig. 7).

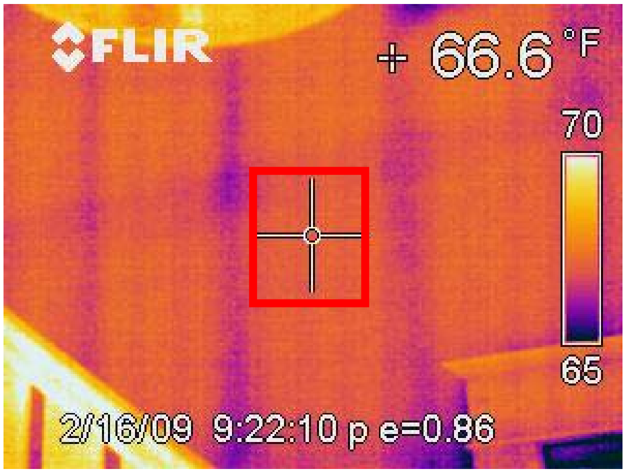


Fig. 6: *Typical Interior Surface Temperature Location*

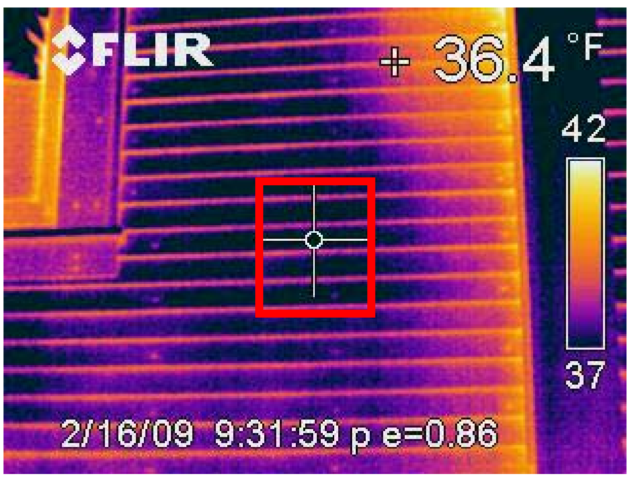


Fig. 7: *Typical Exterior Surface Temperature Location*

Equipment: A FLIR BX-320 Infrared Camera (Fig. 8) was used to provide thermal imaging and surface temperature readings. In addition, FLIR's ThermaCAM Quickview software was used to determine spot temperature readings at other wall locations. Once the initial thermal images were processed, the software interpolated temperature readings based on thermal colors without requiring multiple thermal image pictures.

Average interior ambient air temperatures were recorded by the infrared camera and EXTECH RH390 Psychrometer (Figure 9).

Fig. 8: *FLIR BX-320 Infrared Camera*

Fig. 9: *EXTECH RH390 Psychrometer*

Step 4 - Estimate Framing and Cavity Areas: Walls were separated into two basic areas: framing and cavities. Cavities were defined as any wall areas containing insulation. Quantity take-off estimates of both of these areas were computed to determine their approximate percentage in relation to the overall wall area. Thermal imaging verified framing and cavity locations. Framing included primarily wood studs, and wood bottom and top plates.

Step 5 - Determine Air and Surface Temperatures: Temperature readings were determined at the center of stud framing, at the center of the cavity, and at the outside edge of the framing within the cavity. Thermal measurements were primarily located along four horizontal locations, approximately two feet on center vertically, in order to get an adequate number of framing and cavity temperature readings (Fig. 10).

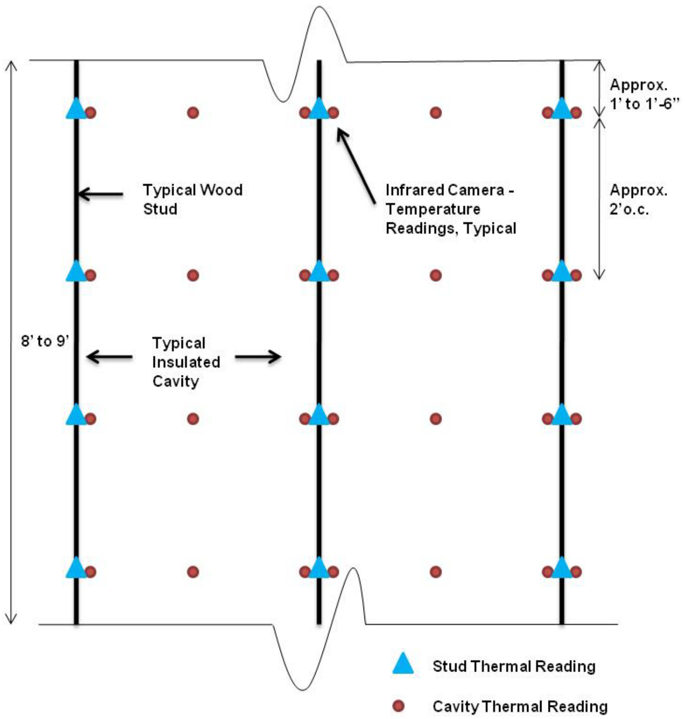


Fig. 10: *Typical Temperature Reading Locations*

4. RESULTS

4.1 - Predicted Wall R-values: Predicted wall R-values were determined by simple material component calculations. (3) The figures below included both stud and cavity R-value calculations (Figures 11-13). The purpose of this information was to demonstrate how thermal bridging affects the whole wall effective R-value. It also allowed comparison and analysis of predicted, prescribed, and actual R-values.

Based on as-built wall conditions, the predicted R-value was 8.28 at the studs (Fig. 11) and 17.4 at cellulose insulated areas (Fig. 12). Fiberglass insulated cavities had a slightly higher R-value of 20.88 (Fig. 13).

R-VALUE for 2X4 WALL at STUD AREAS		
Component	**Thickness**	**R-Value**
Inside Air Film	-	0.68
Interior Plaster	3/4"	0.45
2x4 Nominal Stud Framing	4"	4.56
Horizontal Sheathing Boards	3/4"	0.93
Plywood Sheathing	1/2"	0.62
60 Min. Building Paper	nil	0.06
Cedar Drop-Lap Siding	1/2"	0.81
Exterior Air Film	-	0.17
TOTAL R-VALUE (STUD WALL AREA)		8.28

Fig. 11: *Predicted R-value at Stud Areas*

R-VALUE for 2X4 WALL at CAVITY AREAS (Cellulose)		
Component	**Thickness**	**R-Value**
Inside Air Film	-	0.68
Interior Plaster	3/4"	0.45
Cellulose Insulation	4"	13.68
Horizontal Sheathing Boards	3/4"	0.93
Plywood Sheathing	1/2"	0.62
60 Min. Building Paper	nil	0.06
Cedar Drop-Lap Siding	1/2"	0.81
Exterior Air Film	-	0.17
TOTAL R-VALUE (CAVITY WALL AREA)		17.4

Fig. 12: *Predicted R-value at Cavity Areas (Cellulose)*

R-VALUE for 2X4 WALL at CAVITY AREAS (Fiberglass)		
Component	**Thickness**	**R-Value**
Inside Air Film	-	0.68
Interior Plaster	3/4"	0.45
Fiberglass Insulation	4"	17.16
Horizontal Sheathing Boards	3/4"	0.93
Plywood Sheathing	1/2"	0.62
60 Min. Building Paper	nil	0.06
Cedar Drop-Lap Siding	1/2"	0.81
Exterior Air Film	-	0.17
TOTAL R-VALUE (CAVITY WALL AREA)		20.88

Fig. 13: *Predicted R-value at Cavity Areas (Fiberglass)*

4.2 - Cavity and Stud Wall Areas: Based on an 8' wall height, stud framing composed 17% and cavities 83% of the total wall areas tested. If window and door framing members were added, the total framing would range from 20-30% of the wall area. For purposes of this study, we used a simple wall framing area of 17%.

In order to establish a predictive whole wall R-value, we used the following formula:

Predicted Whole Wall R-value = % Stud Area x (Stud R-Value) + % Cavity Area x (Cavity R-value)

- For walls filled with blown-in cellulose insulation the Whole Wall R-value = .17(8.28) + .83(17.4) = 16

- For walls filled with fiberglass insulation the Whole Wall R-value = .17(8.28) + .83(20.88) = 18.5

Based on this information, both wall types are predicted to satisfy the minimum energy requirement of R-15 required by the 2003 Oregon One and Two Family Specialty Code, as well as the current recommendation of R-13 for ASHRAE 90.1-2007 Standard for residential buildings.

4.3 - Actual Wall R-value: To begin the process of determining Actual Wall R-value, thermal infrared images were first taken at all four wall locations as described in Section 3 above. Temperature spot readings were taken (Fig. 14) and recorded (TABLE A) for framing and cavity areas.

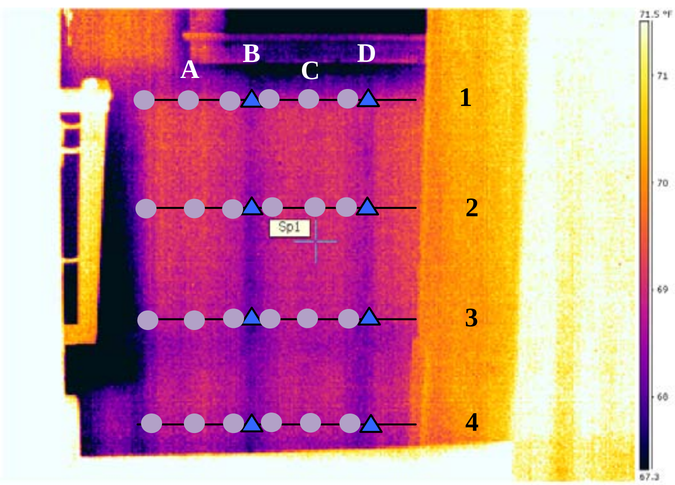


Fig. 14: *Temperature Reading Locations Wall-1*

Using the surface temperatures for stud and cavity areas in Table A below for Wall-1, the average stud and cavity temperatures were calculated at 66.6 °F and 67.2 °F respectively.

Similar to the predictive method calculation listed above, the stud and cavity wall area percentages were used to establish an average interior surface temperature of the exterior wall.

Average Interior Surface Temperature of Exterior Wall = % Stud Area x (Average Stud Surface Temperature) + % Cavity Area x (Average Cavity Surface Temperature)

- Average Interior Surface Temperature of Exterior Wall-1 = .17 (66.6 °F) + .83(67.2 °F) = 67.1 °F

The interior air and exterior surface temperatures were also obtained:

- Exterior Wall-1 Surface Temperature = 37.8 °F

- Interior Air Temperature at Wall-1 = 70.0 °F

This information was then used to find the differences between indoor ambient air and inside (exterior) wall surface temperatures, and the inside (exterior) wall surface and outdoor exterior wall surface temperatures:

- Indoor Air Temperature – Inside (Exterior Wall) Surface Temperature: 70.0 °F - 67.1 °F = 2.9 °F

- Inside (Exterior Wall) Surface Temperature – Exterior Wall Surface Temperature: 67.1 °F - 37.8 °F = 29.3 °

TABLE A: TYPICAL WALL-1 SURFACE TEMPERATURES °F OF CAVITIES AND FRAMING

ROW #	Cavity (Left) A	Cavity (Center) A	Cavity (Right) A	Framing Stud B	Cavity (Left) C	Cavity (Center) C	Cavity (Right) C	Framing Stud D
1	67.1	67.4	67.1	66.6	67.4	67.5	67.4	66.9
2	67.1	67.4	67.2	66.3	67.1	67.4	67.4	67.1
3	67.0	67.1	66.9	66.3	66.4	67.2	67.2	66.7
4	67.1	67.2	67.2	66.3	67.0	67.2	67.3	66.5

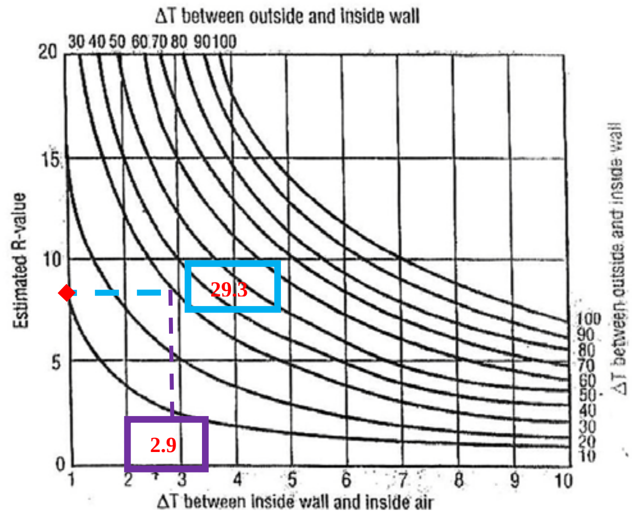
The remaining wall test areas with their corresponding temperature measurements and differences were calculated and compiled (TABLE B).

<u>TABLE B: AIR AND WALL SURFACE TEMPERTURES °F AND DIFFERENCES</u>

	Wall-1	Wall -2	Wall -3	Wall -4
Exterior Wall - Inside Wall Surface Temperature	67.1	66.7	67.5	68.0
Exterior Wall - Exterior Surface Temperature	37.8	37.8	37.7	37.7
Interior Ambient Air Temperature	70.0	70.0	70.1	69.9
ΔT = Ambient Air - Inside Surface	2.9	3.3	2.6	1.9
ΔT = Inside Surface - Exterior Surface	29.3	28.9	29.8	30.3

To complete the process, using the data from Wall-1 in Table B and information provided by the Infrared Training Center (ITC) and the National Comfort Institute, the actual R-value was determined using the graph in Fig. 15. (1, 2)

The remaining wall areas were also graphed and the information was used to establish an actual average R-value comparison chart (Fig 16). The chart includes a breakdown of each wall's associated stud and cavity R-values. In addition, dashed horizontal reference lines are used to compare the actual R-values with predicted (R-16), Oregon Building Code (R-15), and ASHRAE (R-13) R-values.



◆ **Average Wall-1 R- value = approx. 8.5**

Fig. 15: *Average R-value Interpolation for Wall-1 using indoor air, and exterior and interior wall surface temperatures.* (1)(2)

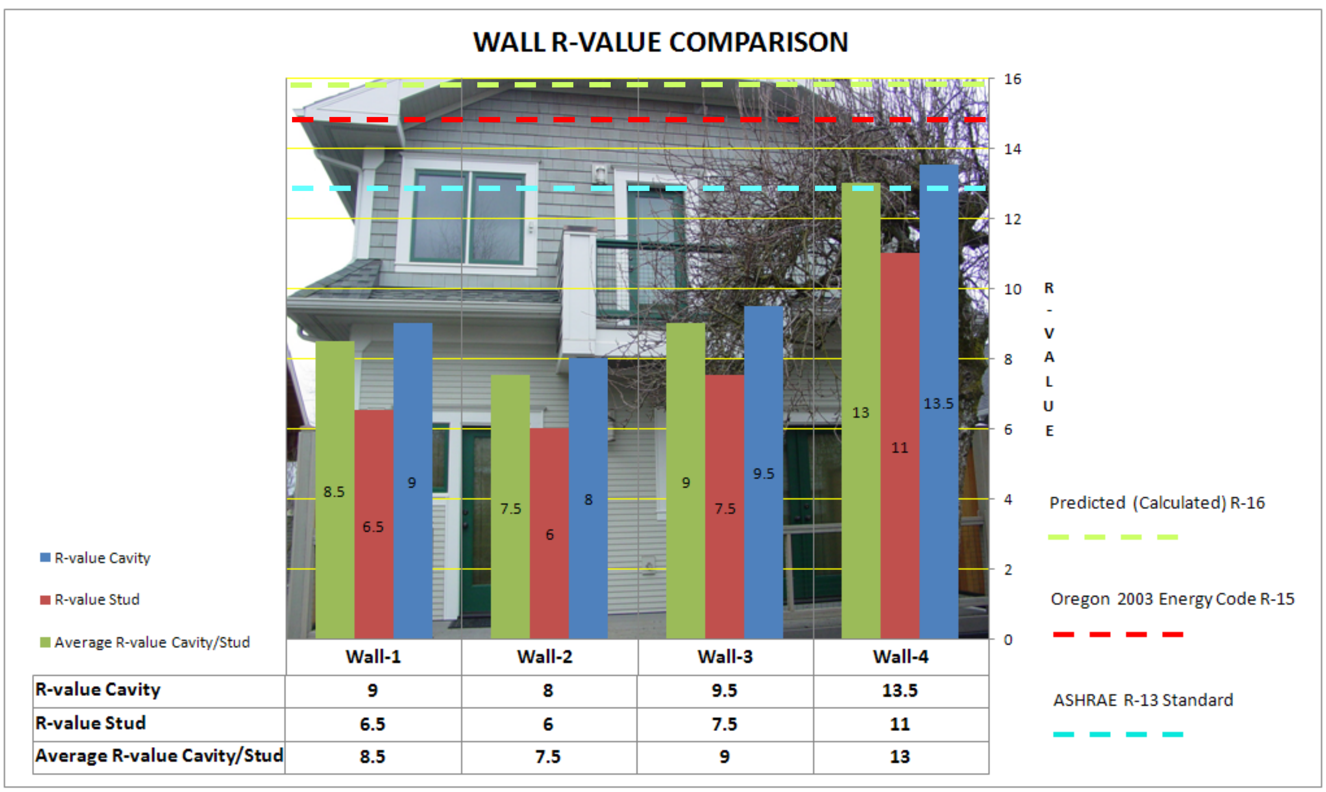


Fig. 16: *Wall R-value Comparison Chart*

5. DISCUSSION

A. The actual average R-values for all walls tested were below the predicted (component method calculation) R-16 value and the 2003 Oregon Building Code R-15 requirement. Only Wall-4 met the minimum R-13 ASHRAE insulation standard. In addition, the results fall short of the R-21 wall insulation base case requirement found in the current 2007 Oregon Residential Specialty Code.

Based on Fig. 16 above, the average whole wall R-value for all four walls was R-9.5. The average R-values ranged from a low of R-7.5 to a high of R-13. The difference in the average R-value is 27% to 41% lower as compare to the three R-value benchmarks.

- Actual Whole Wall R-9.5 compared to ASHRAE Standard 90.1-2007 R-13 = 27% lower
- Actual Whole Wall R-9.5 compared to 2003 Oregon State Building Code R-15 = 37% lower
- Actual Whole Wall R-9.5 compared to Predicted (calculated) R-16 = 41% lower

B. The 17% wall framing area used in the study affected the actual whole wall average R-value by decreasing the insulation value approximately R-.5 as compared to cavity R-values. Additionally, framing including door and window openings would generate a higher 20-30% framing area range. This would further decrease whole wall averages an extra R-.25 to R-.3.

C. During the analysis, a consistent drop in temperature was observed at the cavity areas adjacent to the studs. Twenty-four out of thirty-two temperature readings were recorded where the cavity's center temperature was equal to or greater than readings closest to the wood studs. Some readings fluctuated as much as .8 °F lower. It is thought that this result is due to voids created during hand or mechanically applied insulation installations. During hand applied installations, the insulation mounting tabs are frequently fastened along the cavity (inside) face of the stud creating a depression in the batt insulation along the stud's length. Also, mechanically applied cellulose may not fill the entire inside corner area, between the stud and drywall, creating slight voids in the cavities. Both of these conditions reduce the overall R-value of the cavity insulation, and demonstrate the need to install insulation carefully in order to utilize its full potential.

D. Accurate inside and surface temperature information is critical to this analysis. The increase or decrease of tenth of degree temperature readings during the analysis can have a profound effect on the graph in Fig. 15 and the resultant actual R-value. This is why it is imperative that all interior air and surface temperatures be recorded carefully. One of the important factors in recording accurate field temperatures is making sure that the infrared camera is calibrated on site and to the surrounding conditions prior to recording any infrared readings.

6. CONCLUSIONS

The results in the study appear to have major ramifications in terms of anticipated energy performance and intended savings. The study proved that predicted (calculated) R-values are not accurate when estimating actual wall R-values. Framing area, installation practices, and infiltration have a direct impact on actual R-values.

It also suggests that more extreme construction measures may be necessary or alternative methods considered in reaching a desired R-value result. For example, if a typical wall assembly is known to perform 30% less than what has been predicted at R-21, a higher insulating assembly of R-30 should be considered to compensate for the difference. Further data collection and analysis for common construction assemblies would produce more accurate R-value assumptions, and assist designers when contemplating and choosing final thermal assemblies.

7. ACKNOWLEDGMENTS

Scott Wood, Senior Building Science Consultant and Level II Thermographer at BCRA Architects and Engineers in Tacoma, Washington, for providing helpful information and clarification on several of my infrared camera and heat transfer questions.

8. REFERENCES

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