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Experimental Analysis of Shading Systems and Building Orientation

Results from the Solar Village Project

Study document based on Solar Village measurements and calculated heat-flow analysis

Prepared for project dissemination, educational use, and publication on the project website

Abstract

This study analyses how shading systems and building orientation influence indoor temperature and heat flow in the Solar Village experiment. The project established experimental cube installations in several European countries, each equipped with temperature sensors and online monitoring. Measurements were compared for cubes with no shading, internal shading and external shading. The analysis focuses on summer and winter, because these seasons produce the clearest thermal differences and therefore the most representative results for evaluating the performance of shading systems.

The results show that external shading is highly effective in reducing summer heat gains, while internal shading has an important role in reducing heat loss during winter night-time conditions. The experiment also confirms that glazed surfaces are the most critical part of the building envelope in terms of heat transfer. Comparison across partner countries further shows that the orientation with the strongest temperature differences depends on local solar conditions: west-facing cubes were most critical in Slovenia and Latvia, south-facing cubes in Serbia and Italy, and north-facing cubes in Portugal. Summer measurements for Türkiye are not yet available in a sufficient form for reliable comparison.

1 Introduction

Improving building energy efficiency is one of the central challenges of sustainable construction. Buildings consume a substantial share of total energy, especially for heating and cooling. Solar radiation entering through glazed surfaces can significantly increase indoor temperature during summer, while heat losses through windows contribute to heating demand in winter. Shading systems are therefore a key architectural tool for improving thermal comfort and reducing energy consumption.

The Solar Village project was designed as an educational and research experiment that allows students, teachers and stakeholders to observe the relationship between shading, orientation and energy efficiency under real environmental conditions. By using small insulated cubes with different shading strategies and continuous temperature monitoring, the project creates a practical model for analysing building physics in an accessible and visual way.

2 Experimental Concept

Each Solar Village consists of twelve insulated experimental cubes arranged according to the four cardinal directions: north, south, east and west. Within each orientation group, the cubes represent three shading conditions: no shading, internal shading and external shading. This structure allows direct comparison of how orientation and shading influence indoor temperature and heat flow.

Every cube contains a temperature sensor. The sensors measure temperature at regular intervals and transmit the values to an online monitoring platform. The data are also displayed on a monitor next to the Solar Village installation, so that students, teachers and visitors can observe the measurements directly on site.

3 Monitoring and Data Collection

The monitoring system creates a continuous record of indoor temperature for each cube. Because the cubes differ only in orientation and shading configuration, the measured differences can be used to evaluate the thermal effect of shading systems under similar environmental conditions.

The present analysis is based on temperature measurements combined with heat-flow calculations. The analysis focused on the periods with the largest temperature differences between shaded and unshaded cubes. Spring and autumn were not analysed in detail, because the smaller indoor–outdoor temperature differences during these periods make the influence of

shading less pronounced. Summer and winter provide the most relevant results for practical recommendations.

4 Methodology of Analysis

The analytical approach was based on identifying representative moments with the greatest temperature differences between shaded and unshaded cubes, and then calculating the resulting heat flow. Two seasonal situations were considered:

- Summer, when heat flows from the exterior to the interior because of solar radiation and high outdoor temperatures.
- Winter, when heat flows from the interior to the exterior because indoor temperature is higher than outdoor temperature.

The summer analysis therefore evaluates the ability of shading to prevent heat gain, while the winter analysis evaluates the ability of shading to reduce heat loss.

During spring and autumn temperature differences between indoor and outdoor environments are smaller, which means that the influence of shading is less pronounced.

5 Summer Analysis – Reduction of Solar Heat Gains

The calculations presented in this analysis are based on temperature measurements collected during clear and sunny summer days, when solar radiation has the strongest influence on indoor temperature.

For each Solar Village installation, the analysis focuses on time periods when the largest temperature differences between shaded and unshaded cubes occurred. These moments provide the most representative conditions for evaluating the influence of shading systems on solar heat gains.

For each location, the orientation with the most pronounced temperature differences was selected for detailed analysis. These orientations correspond to the façades receiving the strongest solar exposure during the analysed period.

The selected measurements therefore represent peak summer conditions, when the effect of shading systems on heat flow through the glazed surfaces is most clearly observable.

The following table presents the selected measurement data from the Solar Village installations in Slovenia, Latvia, Italy, Serbia, Portugal and Türkiye. The table includes the date and time of

measurement, outdoor temperature, indoor temperature in the experimental cubes, temperature difference between indoor and outdoor conditions, calculated heat flow through the window and insulated wall, as well as the resulting total heat flow.

SUMMER PTUJ SLOVENIA	To [°C] - outdoor temperature		Ti [°C] - indoor temperature	ΔT [K] - temperature difference	Pwin [W] - heat flow through the window	Pstyro [W] - heat flow through walls	P [W] - total heat flow	Heat flow reduction [%]
8.08.2024	28,4	West without shading	56,6	28,2	419,6	4,1	423,7	
16:00		West with internal shading	50,5	22,1	328,9	3,2	332,1	22
		West with external shading	32,7	4,3	64,0	0,6	64,6	85
SUMMER VALMIERA LATVIA								
11.07.2025	22,3	West without shading	57,94	35,64	530,4	5,1	535,5	
15:16		West with internal shading	44,31	22,01	327,5	3,2	330,7	38
		West with external shading	40	17,7	263,4	2,5	265,9	50
SUMMER MONDOVI ITALIJA								
26.08.2025	27,4	South without shading	62,25	34,85	518,6	5,0	523,6	
15:23		South with internal shading	50,81	23,41	348,4	3,4	351,7	33
		South with external shading	44,31	16,91	251,6	2,4	254,1	51
SUMMER SUBOTICA SERBIA								
9.08.2025	31,2	South without shading	67,38	36,18	538,4	5,2	543,6	
17:27		South with internal shading	42,06	10,86	161,6	1,6	163,2	70
		South with external shading	41,5	10,3	153,3	1,5	154,8	72
SUMMER VILLA VERDE PORTUGALSKA								
9.08.2025	28,1	North without shading	53,25	25,15	374,3	3,6	377,9	
17:27		North with internal shading	44,44	16,34	243,2	2,4	245,5	35
		North with external shading	41,81	13,71	204,0	2,0	206,0	45
SUMMER BURSA Türkiye								
16.08.2025	31,3	West without shading	60,38	29,08	432,7	4,2	436,9	
16:25		West with internal shading	54,88	23,58	350,9	3,4	354,3	19
		West with external shading	54,13	22,83	339,7	3,3	343,0	21

These results clearly show that external shading is the most effective summer strategy. External shading blocks solar radiation before it reaches the glazing surface and therefore prevents the greenhouse effect inside the cube. Internal shading also reduces heat gain, but less efficiently because part of the solar energy has already passed through the glazing.

The results support a clear operational recommendation for summer: external shading should be closed during the day to prevent heat gain, while shading should be opened at night to allow natural cooling.

6 Glazed Surfaces as the Critical Thermal Weak Point

One of the most important conclusions of the Solar Village experiment is that glazed surfaces are the most problematic part of the building envelope in thermal terms. Although walls can be well

insulated, windows allow the majority of heat transfer into and out of the interior. This makes the design, orientation and protection of glazing a decisive factor in building energy efficiency.

Although the walls of the cubes are insulated with expanded polystyrene, the measurements clearly show that the majority of heat flow occurs through the window.

The calculated heat flow values for are:

<i>Slovenia Summer</i>	Heat flow P [W]
Window	419,6
Insulated wal	4,1
Total	423,7

The results show that approximately 99% of the total heat flow passes through the glazed surface, while only about 1% passes through the insulated wall structure.

This clearly demonstrates that glazing represents the most critical part of the building envelope in terms of thermal performance. Without appropriate shading or high-performance glazing, solar radiation entering through windows becomes the dominant factor influencing indoor temperature.

These findings confirm that protecting glazed surfaces with external shading systems is one of the most effective strategies for improving building energy efficiency.

7 Comparison of Results Across Partner Countries

Because the Solar Village concept was implemented in several European countries, the project also provides valuable comparative insight. Although the same experimental principle was used, the orientation showing the largest temperature differences between shaded and unshaded cubes varied according to local climate, solar path and surrounding conditions.

Country	Orientation with strongest summer differences	Interpretation
Slovenia	West	Strong afternoon sun reaches the glazing at a low angle; nearby buildings reduce noon exposure but not afternoon gains.
Latvia	West	Similar solar path to Slovenia; late afternoon solar radiation produces the largest gains through glazing.

Serbia	South	Strong midday solar radiation creates the most pronounced gains through south-facing windows.
Italy	South	South-facing cubes receive the highest summer solar radiation during midday.
Portugal	North	Higher solar altitude, diffuse radiation and reflections make north-facing cubes thermally relevant in southern climate.
Türkiye	West	Afternoon solar exposure produces the highest temperature increase, similar to Slovenia and Latvia; however, temperature differences between shaded and unshaded cubes are smaller due to higher ambient temperatures and increased diffuse radiation.

In Slovenia and Latvia the measurements showed that the largest temperature differences between shaded and unshaded cubes occurred on the west-facing cubes during the afternoon. This behaviour is related to the position of the sun and the surrounding built environment. Around midday the sun is positioned high above the horizon, which reduces direct solar penetration through the windows. However, during the afternoon the sun reaches the west-facing window at a lower angle, allowing solar radiation to enter directly through the entire glazed surface. Because glass allows a large portion of solar radiation to enter the interior, unshaded west-facing windows become a significant source of heat gain. This explains the strong overheating observed in the unshaded cube during the afternoon hours.

Also in Türkiye the measurements obtained from the Solar Village installation show that during summer the highest temperature increase in the experimental cubes occurs on the west-facing orientation. However, the measurements indicate that the temperature differences between shaded and unshaded cubes in Türkiye are smaller than those observed in Slovenia. This can be attributed to the generally higher outdoor temperatures typical for the Turkish climate. Under such conditions, a larger portion of heat gain results from the high ambient air temperature and heat transfer through the construction itself, which reduces the relative impact of direct solar radiation entering through the window. As a result, although shading still contributes to reducing solar heat gains, the temperature differences between shaded and unshaded cubes are less pronounced than in cooler climatic conditions.

In Serbia and Italy, by contrast, the largest differences were observed on the south orientation, where midday solar radiation is strongest. Portugal showed a distinctive pattern, with the strongest differences recorded on north-facing cubes. This is explained by the higher solar altitude of the southern climate, combined with diffuse and reflected radiation.

Across all countries with available summer data, the common conclusion remains the same: external shading significantly reduces heat gains through glazing, regardless of which orientation proves locally most critical.

8 Winter Analysis – Reduction of Heat Loss

During winter the thermal process is reversed: indoor temperature is higher than outdoor temperature, so heat flows from the interior to the exterior. In this season the objective of shading changes from blocking solar heat to retaining indoor heat.

Shading configuration	Calculated heat loss	Change compared with unshaded cube
No shading	379.4 W	—
Internal shading	369.0 W	-2.7%
External shading	143.6 W	-62.0%

The winter calculations indicate that shading strategies also influence heat loss. In practice, internal shading is especially relevant at night because curtains or internal blinds create an additional insulating layer near the glazing. The operational recommendation that emerges from the experiment is therefore: keep shading open during the day to benefit from solar gains, and use internal shading at night to reduce heat loss.

9 Practical Implications for Sustainable Construction

The Solar Village experiment provides several practical recommendations for sustainable building design.

- Use external shading as the primary summer strategy for reducing overheating and cooling demand.
- Treat glazed surfaces as the most critical thermal weak point of the building envelope.
- Design shading according to building orientation; west and south façades often require the strongest summer protection.

- Adapt shading strategies seasonally: summer protection during the day, winter solar gains during the day, internal shading at winter night.
- Use monitoring and real data in education and design to support evidence-based decisions.

These recommendations are directly relevant for architects, engineers, builders, educators and policymakers interested in climate-responsive and energy-efficient buildings.

10 Discussion

The experiment confirms that relatively simple architectural strategies can strongly influence thermal performance. The large reduction in summer heat gains achieved with external shading shows that passive solutions can substantially reduce cooling demand. At the same time, the winter observations demonstrate that seasonal operation of shading systems matters: strategies that are optimal in summer are not automatically optimal in winter.

The comparative country analysis also shows that sustainable design recommendations must always consider local conditions. There is no single universal critical orientation. Instead, solar path, latitude, urban context and reflections can shift the orientation where the strongest heat gains occur. This is precisely why experimental, measured data are so valuable.

11 Conclusion

The Solar Village project demonstrates that shading systems, orientation and glazing design have a decisive influence on building energy performance. The measurements show that external shading can reduce summer heat gains by more than 80%, while internal shading contributes to reducing winter heat loss during night-time conditions. The experiment also confirms that windows are the dominant pathway for heat transfer and should therefore be a central focus of energy-efficient building design.

By combining experimental measurement, digital monitoring and comparative analysis across European regions, the project provides both educational value and practical guidance for sustainable construction. The findings support the development of evidence-based shading strategies that improve thermal comfort, reduce energy use and contribute to more climate-responsive buildings.