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ENERGY PERFORMANCE EVALUATION OF AN OFFICE BUILDING WITH MOBILE SHADING AND INTEGRATED PV CELLS

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Abstract: *The aim of the paper is to outline the energy performance optimisation for a building using mobile shading with integrated PV cells. The case studies show possible energy savings by completely closing the insulated shading blades in the cold nights and therefore increasing the thermal resistance of the glazed façades, respectively by blocking the solar radiation in summer while allowing it in winter. Furthermore, the use of photovoltaic cells decreases the energy demand from conventional sources. Results demonstrate savings in cooling energy demand up to 90%, 25% savings in heating energy demand and 10% collected energy from the PV cells integrated into the shading system of the cooling and heating demand.*

Key words: *energy performance, renewable energy, mobile shading, photovoltaic cells*

1. Introduction

The geometry and intensity of solar radiation vary according to location, in the northern hemisphere the maximum intensity being reached on June 21 and the lowest on December 21. However, the maximum temperatures are reached in July and August, and the minimum temperatures in January and February due to earth thermal mass. In this respect, a shading mobile system shows a great advantage in comparison with a fixed system that cannot be efficient throughout the year, see [3, 5, 6].

External shading devices reduce the amount of incident (especially direct) radiation on the glazed surface, thus affecting the temperature of the internal environment behind. Shading systems must be designed to be effective not only during the summer when the sun reaches the maximum altitude, but also in autumn when temperatures are high. The geometry of shading systems must be designed to meet the cooling demand of the building from mid-spring to autumn, depending on local climatic conditions. The optimal geometry of the shading device can be determined by graphical or analytical methods, see [1].

2. Case Study: Office Building with Mobile Shading System

2.1. Premises

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A 3D model of an office building of average dimensions was designed in the modelling program Archicad [12] (Figure 1) choosing as location the city of Iasi, Romania. In terms of floor number and height, the building fits in the average buildings typology for Europe, USA and China, with 8 levels and 30 m high. The opaque-transparent ratio is in favour of

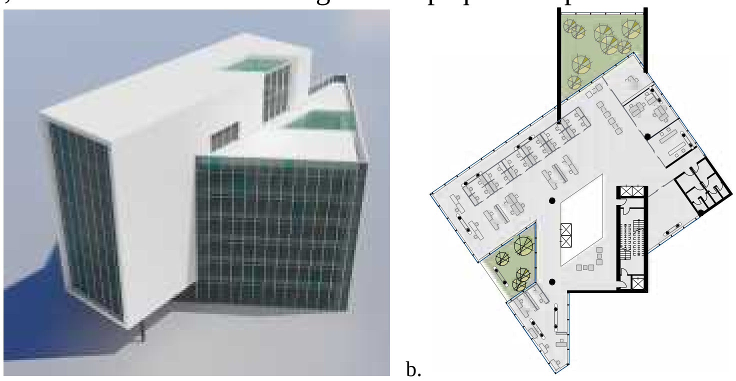

a. b.

Fig. 1.a. *3D representation of the office building;* b. *Office building current floor*

the transparency (glazing ratio: 60,9%), to best highlight the problems and the possibilities for optimizing this type of buildings. To generate results as close to reality as possible, the data are introduced into the simulation programme PHPP.

The structure of the outer walls consists of a layer of high thermal mass inside (brick or reinforced concrete) and a layer of thermal insulation outside. The construction details of the envelope elements are designed to achieve low thermal transmittance values:

- exterior walls U=0.13 W/m^{2}K;
- roof terrace U=0.10 W/m^{2}K;
- floor on ground U=0.10 W/m^{2}K.

The building uses a shading system with mobile horizontal blades (to vary the shading rate monthly and to give the possibility for integrating PV cells), in order to determine:

- the efficiency of a mobile system compared to a fixed one;
- the monthly inclination angles for which the system's energy performance is maximum - in the case of a shading system with movable horizontal elements;
- the energy savings of a shading system whose elements enhance the thermal resistance of glazing during the cold nights.

2.2. Reducing Energy Consumption during the Cold Nights, by Increasing the Thermal Resistance of the Glazed Surfaces

In order to determine, by using the PHPP[3] [13] program, the efficiency of a shading system that closes completely in the cold season's nights, thus preventing the heat loss, the calculation of energy performance included the scenario where the blades are completely closed, and the results are to be interpreted depending on the sunny hours during the day and the hot summer nights, when they must remain open. The proposed scenarios aims to facilitate the evaluation of a mobile shading system with wooden blades (case study a.) and of another one, having horizontal polycarbonate blades with aerogel thermal insulation (case study b.).

a. Mobile shading system with horizontal wooden blades

Thermal characteristics of the curtain-wall façade:

- triple-glazing: Ug = 0.49 W/m^{2}K, g = 0.47
- frame: Uf = 0.63 W/m^{2}K, ϕ_{spacer} = 0.043 W, $\phi_{installation}$ = 0.040 W

[3] Passive House Planning Package

- closed wooden blades during nights
- curtain wall with closed wooden blades U = 0.554 W /m2K.

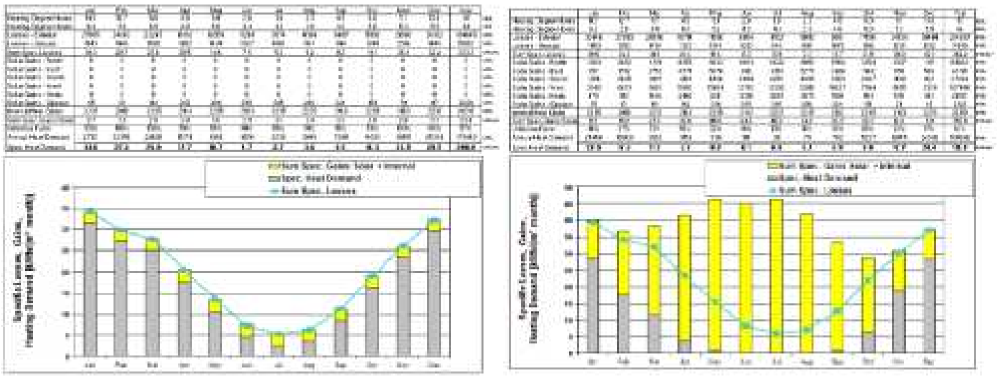


Fig.2. *Monthly heating energy demand in the following cases: a. wooden blades completely shut down; b. building without a shading system*

Calculation of energy losses by closing the wooden blades during the night Table 1

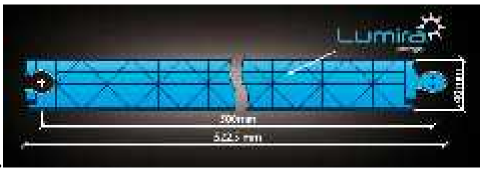
	Number of sunny hours [h]	Heat losses to ground [kWh]	Specific heat losses without shading device [kWh/m^2]	Specific heat losses to ambient without shading device [kWh]	Heat losses with closed shading blades [kWh]	Heat losses with closed shading blades during night [kWh]	Specific heat losses [kWh/m^2]	Energy savings by closing the blades duting night [kWh/m^2]
Jan.	8.9	1450	39.48	32446	27885	29576	36.14	3.34
Feb.	10.28	1353	34.18	27993	24063	25746	31.56	2.62
Mar.	11.83	1494	31.88	25876	22247	24036	29.74	2.14
Apr.	13.58	1393	23.42	18714	16102	17580	22.1	1.32
May	15.05	1347	15.44	11906	10254	11290	14.72	0.72
Jun.	15.88	1003	8.27	6094	5261	5812	7.94	0.33
Jul.	15.55	948	5.92	4132	3574	3936	5.69	0.23
Aug.	14.25	900	6.98	5092	4394	4808	6.65	0.33
Sep.	12.6	1075	12.74	9861	8487	9208	11.98	0.76
Oct.	10.93	1166	21.85	17596	15130	16253	20.29	1.56
Nov.	9.36	1218	30	24531	21086	22430	27.54	2.45
Dec.	8.53	1362	37.05	30444	26162	27684	33.83	3.21

In order to calculate the annual energy demand for heating, it will be assumed that the shading system's blades will be open only during the day; calculation is based on the monthly average duration of the daily number of sunny hours. At the same time, according to Figure 2, which illustrates the monthly energy demand for heating, in June, July and August, the blades will remain open to allow cooling during the nights. Considering the data presented in Table 1, this solution will allow the energy loss to be reduced by 19.01 kWh/m^{2}year, thus reducing the heating energy demand by 16.24%.

b) Mobile shading system with horizontal polycarbonate blades thermally insulated with aerogel (Figure 3.a.)

Thermal characteristics of the curtain-wall façade:

- triple-glazing: Ug = 0.49 W/m^{2}K, g = 0.47
- frame: Uf = 0.63 W/m^{2}K, ϕ_{spacer} = 0.043W, $\phi_{installation}$ = 0.040W
- curtain wall with closed blades with aerogel thermal insulation: U = 0.178 W/m^{2}K

a. 

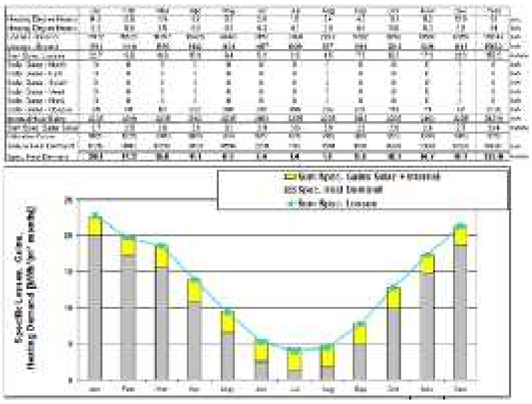
b. 

Fig. 3.a. *Alveolar polycarbonate blades filled with aerogel [11]* b. *Monthly heating energy demand in case of total shutting of the insulated blades*

Calculation of energy loss by closing the wooden blades during night Table 2

	Number of sunny hours [h]	Heat losses to ground [kWh]	Specific heat losses without shading device [kWh/m^2]	Specific heat losses to ambient without shading device [kWh]	Heat losses with closed shading blades [kWh]	Heat losses with closed shading blades during night [kWh]	Specific heat losses [kWh/m^2]	Energy savings by closing the blades duting night [kWh/m^2]
Jan.	8.9	1543	39.58875	32446	17972	23339.44	28.98187	10.60688
Feb.	10.28	1440	34.28214	27993	15520	20862.6	25.977	8.305144
Mar.	11.83	1590	31.99107	25876	14357	20034.91	25.18765	6.803424
Apr.	13.58	1482	23.52333	18714	10425	15115.19	19.33161	4.191718
May	15.05	1434	15.53779	11906	6663	9950.798	13.26046	2.277325
Jun.	15.88	1067	8.340788	6094	3450	5199.447	7.298855	1.041933
Jul.	15.55	1009	5.987989	4132	2360	3508.108	5.26131	0.726679
Aug.	14.25	957	7.045584	5092	2877	4192.156	5.997489	1.048095
Sep.	12.6	1144	12.81809	9861	5502	7790.475	10.40645	2.411648
Oct.	10.93	1241	21.94043	17596	9769	13333.55	16.97573	4.964701
Nov.	9.36	1296	30.08205	24531	13598	17861.87	22.31416	7.767881
Dec.	8.53	1449	37.14743	30444	16856	21685.4	26.94584	10.20159

Using aerogel as thermal insulation for the shading system (Figure 3.b.), energy saving by closing them during cold nights reaches 60.31 kWh/m^{2}year (Table 2), 31.15% more than energy saving by using wood for the shading system. Annual energy demand for heating therefore decreases by 51.54%, from 117 kWh/m^2 year to 56.69 kWh/m^2 year.

Case studies demonstrate the contribution of this envelope solution to reducing energy demand by increasing the thermal resistance of the glazing by total closing of the blades, especially in the period from October to April.

2.3. Diminishing the Energy Consumption for Cooling by Blocking the Solar Radiation

The mobile shading system is analysed in the PHPP. The percentage of the solar radiation used each month of the year is considered as the starting date, thus determining the degree of the required monthly shading (Figure 4, Tables 3 and 4). Therefore, a graphical method is used to trace the inclination angle of a shading system with horizontal mobile blades, that sum up an overall length of 3.5 metres to fully cover the glazed area when closed (given that shading systems with horizontal elements that sum up the same length and inclination are equivalent systems), see: [1, 4, 7, 10].

Monthly specific solar gains and utilisation factor Table 3

	Heating degree hours - exterior [kKh]	Heating degree hours - ground [kKh]	Sum spec. losses (exterior + ground) [kWh/m^2]	Sum spec. gains solar (external + internal) [kWh/m^2]	Utilisation factor	Annual heat demand [kWh]	Spec. heating energy demand [kWh/m^2]
Jan	14.7	6.3	39.5	11.5	90%	24456	28.5
Feb	12.7	5.8	34.2	19.2	78%	15069	17.6
Mar	11.7	6.5	31.9	27	64%	9892	11.5
Apr	8.5	6	23.4	37.8	43%	3159	3.7
May	5.4	5.8	15.4	45.6	25%	730	0.9
Jun	2.8	4.3	8.3	44.9	12%	114	0.1
Jul	1.9	4.1	5.9	46.2	7%	38	0
Aug	2.3	3.9	7	41.9	10%	78	0.1
Sep	4.5	4.6	12.7	32.5	29%	792	0.9
Oct	8	5	21.9	22.3	60%	5527	6.4
Nov	11.1	5.3	30	12.3	84%	16045	18.7
Dec	13.8	5.9	37.1	8.9	93%	24368	28.4
Year	97	64	267.2	350	33%	100266	116.8

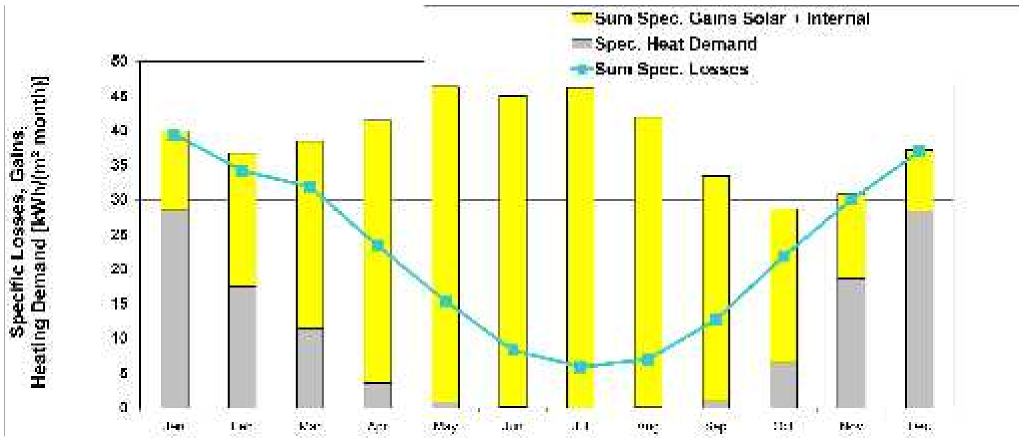


Fig. 4. *Monthly specific losses, gains and heating energy demand*

Necessary shading degree based on the solar radiation utilisation factor Table 4

	Ian.	Feb.	Mar.	Apr.	May	Jun.	Jun.	Aug.	Sep.	Oct.	Nov.	Dec.
Solar gain utilisation factor	90%	78%	64%	43%	25%	12%	7%	10%	29%	60%	84%	93%
Necessary shading degree	10%	22%	36%	57%	75%	88%	93%	90%	71%	30%	16%	7%

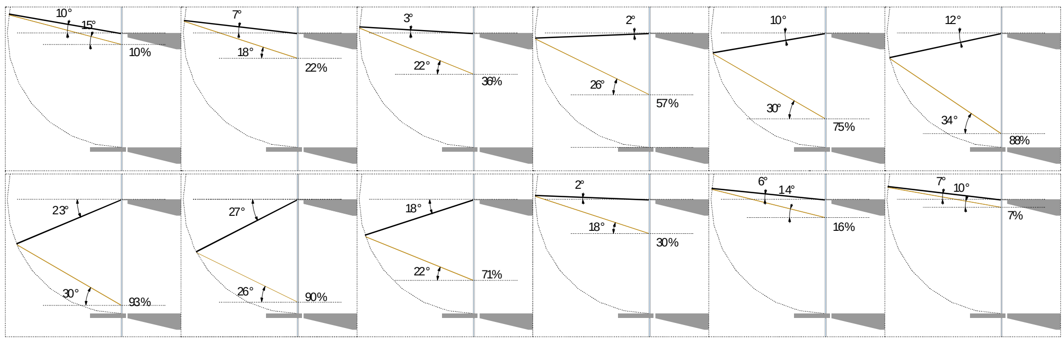


Fig. 5. *Inclination angle for a shading system with mobile horizontal blades to reach the necessary shading degree monthly*

Monthly inclination angle for the shading system blades Table 5

	Ian.	Feb.	Mar.	Apr.	May	Jun.	Jun.	Aug.	Sep.	Oct.	Nov.	Dec.
Inlination angle	-10^o	-7^o	-3^o	2^o	10^o	12^o	23^o	27^o	18^o	-2^o	-14^o	-10^o

Cooling energy demand [kWh/m^2] Table 6

	Ian.	Feb.	Mar.	Apr.	May	Jun.	Jun.	Aug.	Sep.	Oct.	Nov.	Dec.
Building without shading	0.6	3.4	8.2	21.6	36.1	41.9	46.4	38.7	22.2	7.4	1.1	0.3
Building with mobile shading	0.3	1.3	2.4	4.1	3.0	1.1	0.9	0.8	2.2	3.0	0.5	0.2
Savings	0.3	2.1	5.8	17.5	33.1	40.8	45.5	37.9	20	4.4	0.6	0.1

The graphics in Figure 5 determine the inclination angles for each month, considering a shading system with mobile horizontal blades with the summed length of 3.5 metres in order to cover the entire surface area when closed (Table 5).

In order to establish the heating and cooling energy demand in case of integrating a mobile shading system with horizontal elements that monthly modify their inclination angle, the monthly determined degrees of shading were introduced in the PHPP program, calculating for each simulation the monthly energy demand (Table 6).

Taking into account that the minimum inclination of photovoltaic panels is 1^o, this angle is considered for the period October – March. Table 5 illustrates the simulation results, highlighting 91.2% savings in cooling energy demand, from 228 kWh/m^2 year to 20 kWh/m^2 year. In the period of April-September, when the inclination angle of the shading elements varies between 2^o and 18^o, energy savings are considerable.

3. Integration of Renewable Energy Sources

This case study starts from the premise of integrating photovoltaic panels into the horizontal elements of the shading system, that have the same inclination angle as the shading systems blades, changing their position monthly.

By using the SolarPro [14] program, for the south-western façade of the office building, the energy obtained by integrating photovoltaic cells into the shading system is calculated. Solar-Fabrik, SF 125-120 photovoltaic panels were selected from the program database, with dimensions of 1.485/0.663 m and a capacity of 120 W. This type was chosen to get as close as possible to the width of 1.48m in order to avoid mutual shading (see [2, 8, 9]). At each level, the system is composed of two vertical (1,326 m) and 16 horizontal panels to obtain optimum results.

For the months in which the inclination angle is negative, a minimum inclination of 1^o will be considered for the photovoltaic panels (Table 7).

The energy obtained annually amounts to 29 202,45 kWh, resulting in 34,02 kWh/m^{2}year energy saving in heating energy demand.

Energy collected by the photovoltaic panels integrated into the shading system Table 7

	Ian.	Feb.	Mar.	Apr.	May	Jun.	Jun.	Aug.	Sep.	Oct.	Nov.	Dec.
Incl. angle	1^o	1^o	1^o	2^o	10^o	12^o	23^o	27^o	18^o	1^o	1^o	1^o
Energy AC [kWh]	1223.77	1584.10	2451.01	2761.48	3414.36	3487.56	3589.47	3456.45	3364.14	1931.51	1045.07	893.53

Thus, the energy demand for the proposed office building with mobile shading system where photovoltaic panels are associated with the shading elements on the south-western façade and the upper terrace roof is as follows:

- heating energy demand 6.49 kWh/m^{2}year (from 117 kWh/m^{2}year):
- 60.31 kWh /m^{2}year reduction by closing the shading system during cold nights;
- 34.02 kWh/m^{2}year by applying photovoltaic panels to the southwestern façade;
- 16.18 kWh/m^{2}year by integrating photovoltaic panels on the upper terrace roof;
- cooling energy demand 20 kWh/m^{2}year (decreases from 228 kWh/m^{2}year):
- 208 kWh/m^{2}year reduction in cooling energy demand by blocking unwanted solar radiation with the shading system.

The calculations show the efficiency of the mobile shading system in reducing energy consumption, both by blocking heat input in the summer and by increasing the thermal resistance of glazed area during the cold nights from October to April.

4. Conclusions

The results of the case study are used to illustrate a comparative analysis of the energy performance: the case study building and a similar building, traditionally equipped, with some of the relevant energy characteristics presented in Figure 6.

Integrating a mobile shading system with photovoltaic panels proves to have a significant impact on the building energy efficiency. The heating and cooling energy demand decreases 13 times, from 345 kW/m^{2}year to 26.49 kW/m^{2}year, the building enrolling into the category of highly energy efficient buildings, in spite of its large glazing area and orientation (Figure 7).

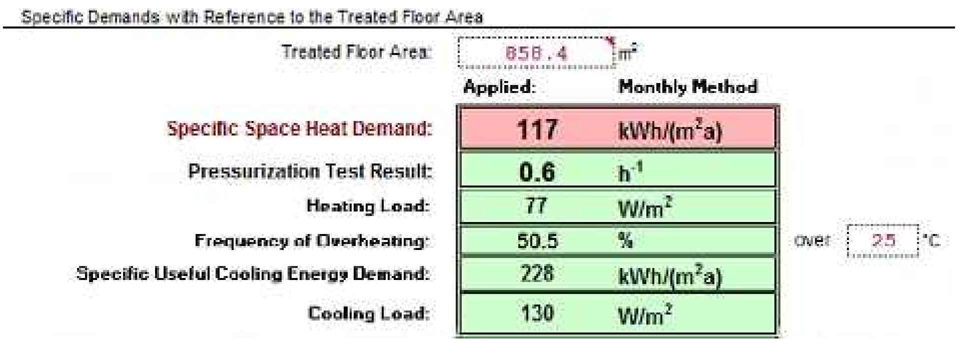


Fig. 6. *The annual heating and cooling energy demand and the overheating frequency for the traditionally equipped building*

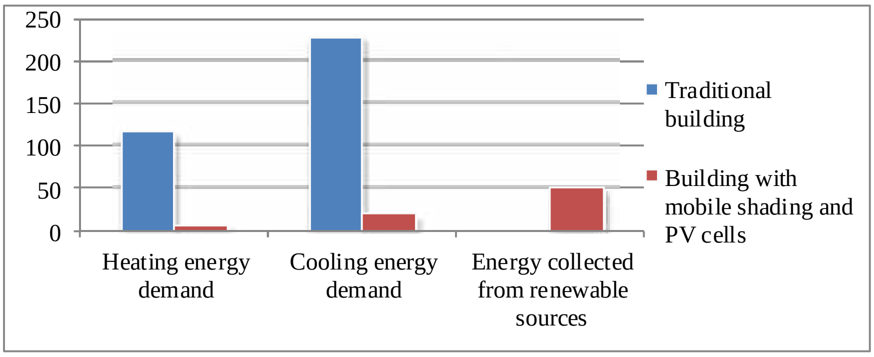


Fig. 7. *Comparative results for the traditional building and the building with mobile shading and integrated PV cells*

4.1. Heating Energy Demand

For the traditional building, the heating energy demand is 117 kW/m^{2}year while for the same building with a mobile shading device with integrated PV modules this value decreases to 6.49 kW/m^{2}year (5.55%), by means of either: i) closing the shading system during cold nights; ii) applying photovoltaic panels to the south-western façade; iii) integrating photovoltaic panels on the upper terrace roof.

4.2. Cooling Energy Demand

The cooling energy demand decreases more than 11 times, from 228 kW/m^{2}year, for the building traditionally equipped, to 20 kWh/m^{2}year for the building with a mobile shading system.

4.3. The Ratio of Energy Consumption from Non-renewable to Renewable Sources

While the traditional building does not use any renewable energy sources, the building with dynamic façade and integrated PV cells collects enough energy to reduce the energy demand for heating and cooling (of 76.69 kW/m^{2}year), with 50.02 kW/m^{2}year (i.e. 65.46%), the rest of 34.54% being supplied from non-renewable sources.

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