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SOLAR ENERGY REFLECTED FROM FACADE AND SEARCH OF OVERHEATING ZONES

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Abstract- Architects use complicated forms of facades in modern architecture that includes facades transformation and uses parametrization. Implementation of surfaces that have analytical description creates possibility to find their carrying capacity and other engineer calculations, to find parameters regarding architectural physics and other applied tasks. Modern facades design provides for using glass with various coatings, polished metal as finishing materials. Concave facade reflects sunrays that create zones of energy concentration. If to consider reflected energy as ∞^2 of rays, it is possible to pick out the surface of rays Λ reflected from one of the generatrixes of facade as analytic reflective surface. The surface Λ have focal lines that are zones of energy concentration. A set of generatrixes of facade surface creates a set of surfaces Λ_1, $\Lambda_2 \ldots \Lambda_n$. In general case we can solve the task to concentrate solar energy or to avoid overheating. The task depends on sphere of implementation. Facade designing needs to predict reflective zones that lead to dangerous concentration of solar ray's energy. The reflections from generatrixes of surfaces have to be analyzed to estimate different types of reflections. Sound reflections for acoustic properties. Light reflections for lighting from natural or artificial source. Moreover, the solar reflections analysis as a theme of this article have to estimate damage from reflected solar energy. Press and some internet publications mention problems caused by this energy. Solar concentrated rays reflected from facades melt cars and burn hairs of people on streets and hotels. Such concentrations of reflected rays can be a cause of appearing of overheating zones in windows of opposite buildings. In this case, architect have to solve problem of energy saving in sphere of sun proofing and dwelling conditioning. The article analyzes geometrical and energy components of reflected solar rays, the search of reflection zones on facades, surfaces of reflected rays with double lines. The double lines are zones of overheating. Geometrically they are focal points or lines for reflected rays. Energy component of insolation can be calculated to estimate temperature level in focal areas. Geometric and analytical calculations give ways for overheating protection.

Keywords: Congruence, Surface of Normal, Surfaces of Reflected Rays, Solar Rays, Overheating.

1. INTRODUCTION

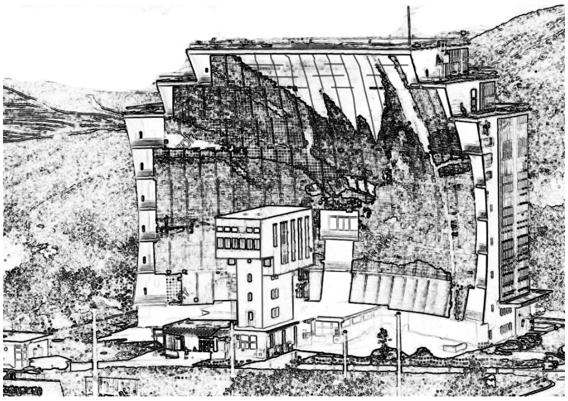
The scientific experience of study of reflected solar energy is represented widely in literature and internet. French solar furnace was built in 1970 in the Pyrenees-Orientale at Odeillo (Figure 1a). In Soviet Union in 1981, the solar furnace was opened in Uzbekistan. Both concentrators are parabolic mirrors approximately 50-meter diameter, both produced temperature 3500 °C and 1 MW energy. It is well known a large number of concentrating solar power stations all over the world. A number of examples can be continued. In addition, these examples are the positive links of reflected solar energy.

However, such properties of reflected solar rays in architecture create problems. Modern facades consist of polished glass or metal materials. In addition, concave forms became a common case. All this together create risk of overheating of areas near buildings. According to publications, such overheating took place in many places in the world. As a result, damaged cars, excess heat in opposite houses, dried up or cracked natural objects.

Two well-known buildings of architect Raphael Vinoli had problems with reflected solar energy. Walkie-Talkie skyscraper, Fenchurch Street, London, 20 (Figure 1c) and Vrada Hotel in Los Angeles (Figure 1b) that respectively have height 160 meters and 176 meters. These buildings have concave surfaces that create lens effect for solar rays. "Death ray" was the definition of this problem in press.

Unfortunately, the result of reflection was damaged road covering, burned people's hair and private things, peeling facade paint on located nearby buildings. One more example is Walt Disney Concert Hall (Figure 1d). It was built in Los Angeles in 2003. It is known fact that investors were forced to change polished parts of concave panels to matte ones. The cause was lens effect that had disturbed townspeople and damaged asphalt and buildings.

There are not isolated cases. Magazines, newspapers and internet editions mentioned many of such problems. The best way to solve them on design stage.



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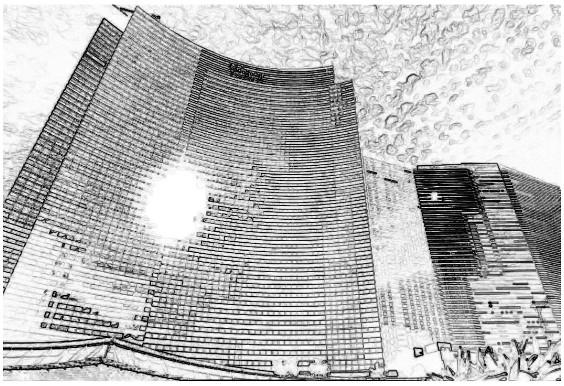

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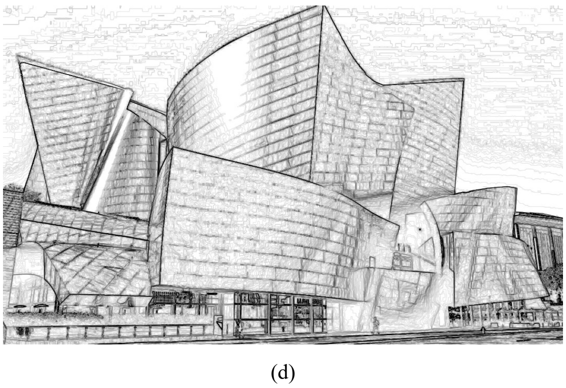


(d)

Figure 1. Complex forms of facades in modern architecture, a: Odeillo Solar Furnace, France, b: Hotel Vrada, Los-Angeles, USA, c: Hotel Walkie-Talkie, London, GB, d: Walt Disney Concert Hall, Los Angeles, USA

2. THE ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Publications [1, 2, 3] give basement for research of surfaces of various types in general and reflected rays in applied tasks in acoustics, insolation and other spheres. Using synthetic geometry methods gives visual control possibilities to construct surfaces of reflected rays with self-intersections that shows zones of concentration of rays. The encyclopedia [4] provides visualization and equations of analytical surfaces. The source [5] gives analytical description of sunlight reflections. Article [6] analyses equations and construction of reflected rays as surface.

Sources [8, 9, 10, 11] give methods of calculation of energy efficiency of buildings where thermal radiation is taken into account depending on the apparent temperature of the atmosphere. Researches [12, 13, 14, 15] analyze different methods of sky temperature, that study transferring of thermal radiation on horizontal surface. In our case, it is possible to interpolate data to vertical surface of facade.

Sources [16, 17, 18, 19, 20] analyze physical phenomena as geometric model presented as surface theory. Ray representation of solar, light or sound energy allows extracting surfaces of rays from congruence of rays that can be used the same way in reflections. Problems of solar radiation input and overheating are considered in [21, 22, 23, 24, 25, 26].

3. PURPOSE

Research of double lines in surfaces of reflected solar rays as geometrical task and calculation of overheating as energy estimation task.

4. RESULTS

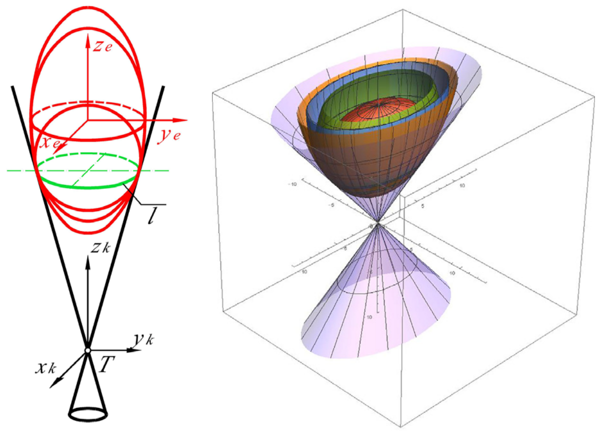
To research reflections it is necessary to consider reflective surfaces according to specific classification, surface of normal and, as a result, surface of reflected rays. The source of light is improper point. It is proposed to consider the reflective surfaces as classification of surfaces according to types of surfaces of normal along their generatrices. Reflective surfaces are divided on five types, each have one type of reflection line and surface of normal (Table 1).

For each group of reflective surfaces were received equations of surfaces of normal and surfaces of reflected rays. Inside each group, we also have common surfaces of normal that leads to common surfaces of reflected rays. Therefore, it is possible to change reflective surfaces by another surface from group if to keep the condition of common surface of normal, consequently, tangent surface. Figure 2 shows one parametric set of surfaces with common tangent surface of cone and common surface of reflected rays.

Table 1. Types of reflective lines and surfaces of normal in classification of reflective surfaces

Group number	I	II	III	IV	V
reflective curve on surface	straight line	straight line	circle	2nd order curve	2nd order curve
surface of normal	beam of parallel lines	hypar	circular cone	flat bundle of straight lines	4st order surface

Each group has also their type of surface of reflected rays for above-mentioned reflective lines along tangent surface. Appearance of equation of the surface of reflected rays depends on type of reflective surface, but appearance of the surfaces will be the same. From the specified properties we can made some conclusions. The first is the surface of reflected rays for I and II groups have no self-intersections, for III-IV groups have such self-intersections. Therefore, these self-intersections are the potential zones of overheating. Architect can use these properties choosing form of facade. The second, it is necessary to check one parametric set of surfaces of reflected rays from minimum two families of generatrices of reflective surfaces. Because these sets can have different intersections. The third, it is possible to correct facade covering to avoid reflections that lead to overheating, to change facade form in these reflective zones or use kinetic screens for sun proofing. The fourth, when architect ones choose facade form with needed reflective properties along some line, he can use one parametric set of facade surfaces with the same reflective properties along this line.



(a) (b)

Figure 2. One parametric set of ellipsoids with common tangent surface of 2nd degree cone, (a) Drawing of one parametric set of ellipsoids with tangent cone, (b) Visualization in Mathematica

where, l is tangent line of cone and set of ellipsoids as well as common line of the set. For each type of reflective surfaces, we have congruence of normal. The surface of normal we will receive due to immersion of some curve in the congruence. For each considered group of reflective surfaces we will obtain one type of surfaces of normal (Table 1). According to ray representation of geometric model of reflections, all rays, reflected from surface are ∞^2 rays. For each group of our reflective surfaces we will receive one type of surface of reflected rays. From shown classification, we can consider reflective surfaces of III, IV, V groups for case of the search of overheated zones. Exactly these surfaces have concave forms. Surfaces of rays reflected from these surfaces have double lines of self-intersection. These double lines mean that in each their double point two rays have intersection.

Therefore, from energy point of view, straight solar ray and two reflected rays comes to this point. This is true for ruled surface of zero Gaussian curvature. For ellipsoid or hyperboloid of two sheets, we have four rays in one intersection point in general case. In a particular case, more rays can have intersection in one point and even all reflected rays come to one point for paraboloid. Sun, as an improper source, can be set by improper plane with normal vector $\{K; L; M\}$. This vector will be direction vector for sunrays. Therefore, the sunrays in analytical equation will be parallel lines with direction of normal of plane in infinity. The equation of solar ray will be:

$$x = x_a + Kt$$
$$y = y_a + Lt \qquad (1)$$
$$z = z_a + Mt$$

where, $A(x_a, y_a, z_a)$ is reflective point on the reflective surface. To receive surface of reflected rays it is necessary to set line on the reflective surface. If this line is ellipse, we need to change $A(x_a, y_a, z_a)$ to ellipse equation. The result is cylinder of incident rays:

$$x = a\cos u + Kt$$
$$y = b\sin u + Lt \qquad (2)$$
$$z = c + Mt$$

According to one of the known algorithms, it is possible to receive a surface of reflected rays. The article [5, 6, 7] describes writing equation of reflected rays for sunlight. Figure 3 illustrates visualization of the surface of rays reflected from cone of 2-nd order. Reflections were constructed from perpendicular to axis elliptical section of the cone. The source is in improper point. The surfaces of reflected rays were visualized in Mathematica with different angles of falling rays. Figure 3 also shows double lines of self-intersections of the surface.

Figure 4 illustrates the scheme of self-intersection of the solar rays reflected from the surface of cylinder of 2nd order as a facade. Horizontal plane is a ground. This drawing shows parallel solar rays that reflect from cylindrical facade. The figure considers three lines – upper floor line, middle floor and first floor. As we can see, one parametric set of reflected surfaces intersects earth's surface. Some line intersections coincide reflected surface self-intersection line. During Sun movement, we receive places on earth that take solar heat from straight rays and reflected ones. The reflected rays heat some areas from two places due to self-intersections or intersections on surfaces from set on the level of earth. Therefore, we found areas with constant heating. In case of other more complicated forms of facades, the areas of overheating can take rays from more than two sides that gives higher heating temperature.

For overheating estimating, we need to combine geometric and analytical methods. Due to geometrical construction, it is possible to see the quantity of rays that come to given place or what area reflects solar energy to this place. Analytical calculations allow receiving energetic level of incoming solar energy and count temperature and time of heating.

where,

m: Self-intersection line of the surface of reflected rays above, on and under the earth

n: Intersection line of the surface of the reflected rays with surface of earth

Σ: Plane that set the improper source

Ω: Reflective surface of facade

Π: Plane of earth

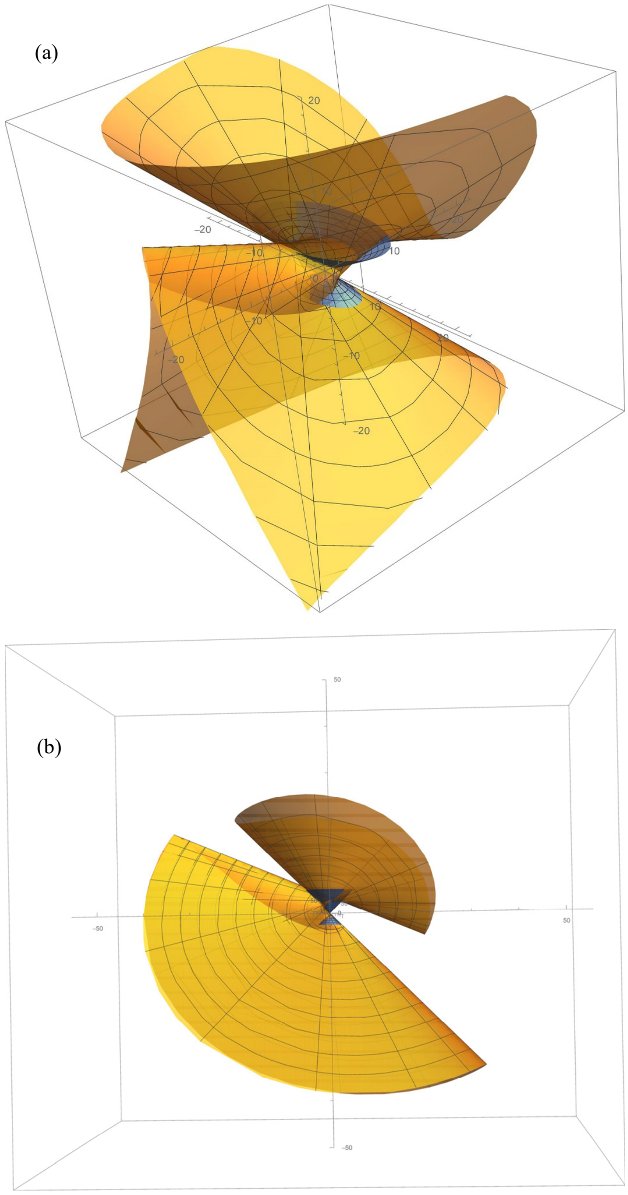
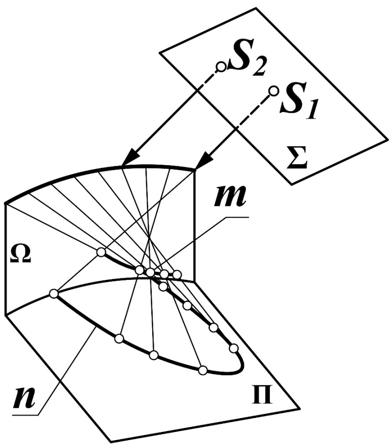
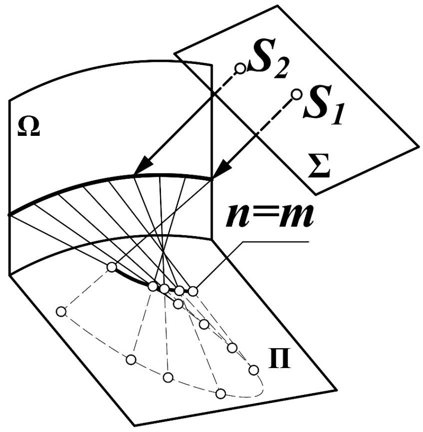


Figure 3. Visualization of reflected from cone of 2nd order rays as the surfaces of reflected rays with improper source of solar rays, (a), (b) Different positions of light source



(a)



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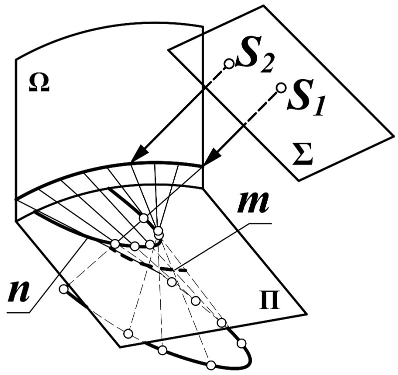

(c)

Figure 4. Three types of solar rays' reflections from elliptical generatrix of cylinder a: Upper line of cylindrical facade Ω reflects rays to ground Π, b: Middle line of cylindrical facade Ω reflects rays to ground Π, c: Lower line of cylindrical facade Ω reflects rays to ground Π

The geometric way allows defining quantity of incoming energy to one place in geometric representation, for example, area of reflected energy. Due to ray theory, from congruence of lines we can extract one parametric set of surfaces of reflected rays. This way gives possibility to define set of double lines of the surfaces. Their concentration on one area gives zones of high temperature.

The need for such calculations is clear. It has positive component and negative. The positive is to use solar rays' reflections for heating system, heat pumps, hot water, for enterprises, in general, for energy saving for receiving heat. The negative is to prevent overheating that can damage surfaces, property, people or lead to energy loss.

Solar energy in Ukraine on ground or sea level in south regions reaches 1000 W/m^2 in summer time. In winter falling to 250 W/m^2. Middle latitudes have approximately 800 W/m^2. In the sea level, the maximum income of solar radiation is up to 1020 W/m^2. Total amount of heat that enter the area unit is

$$Q_{heat} = S_{sol} + D_{cs} + R_{refl} \quad (3)$$

where,

S_{sol}: Straight solar light on considering area, (W/m^2)
D_{sc}: Scattered solar radiation, (W/m^2)
R_{refl}: Solar radiation, reflected from earth, facades and other surfaces, (W/m^2)

The S_{sol}, D_{sc}, R_{refl} depend on ray incidence angle, albedo of reflective surfaces, cloudiness, solar radiation intensity, body convection, wind and other factors.

For estimation the negative influence of radiation, we can neglect factors that reduce solar energy such as cloudiness. Facade glass can absorb 30-70% of solar energy, therefore, it can reach 700 W/m^2. Straight solar light and three-square meters from cylindrical facade can give 3.1 kW/m^2, ellipsoid up to 3.8 kW. The energy level can be much bigger with some facade forms. It is well known fact that from straight solar light the heat of asphalt reaches 60 °C, black car up to 82 °C. The temperature can be bigger in case of reflected rays. We also understand the danger of such heat of tank with diesel, patrol or gas. Closed tank, as a rule, is safe. However, general flash point of petroleum products reaches 35-120 °C, flammable gasolines 28 °C, kerosenes 28-45 °C, motor, diesel fuel, fuel oils 45-120 °C. And this must be taken into account.

The positive case, we can consider solar water collector. It consists of 15 vacuum tubes with area 3m^2, liquid volume 150 litters. The water heat capacity is c_{water}=1.163 Wh/kgK, for heating 1 liter of water for 1 degree it is necessary 1.163 W. If we need to heat this collector from 10 to 45 °C, it can be done by 0.5 hour. It can be used for energy saving technology.

Therefore, finding areas of concentration of solar rays gives the possibility to use this knowledge in two directions. The defined zones of overheating allow constructing reflective zones for using special facade materials to avoid dangerous influence of sun rays. From the other side, zones of concentration of reflected solar rays can be used for energy saving technologies, for generation of electric and heating power. The paper is an extension of the researches of overheating in energy saving sphere. In previous publications were pointed methods of defining the Sun position with solar maps and its influence to overheating of dwelling.

5. CONCLUSIONS

One parametric set of surfaces of rays reflected from concave surface of facade leads to self-intersections as double lines of surfaces, as well as intersections of reflected rays with earth. Finding areas on facade that give overheated zones on earth and opposite buildings is important task to prevent damage from solar rays. From the other side, zones of reflected rays' concentration allow to produce heating or electric power, that are energy saving technologies and generation of renewable energy. The way to define such areas and zones is synthetic geometric method of construction of reflections and method of mathematics models for automatized construction.

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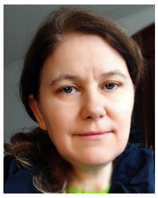

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