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Обоснование параметров, используемых при изучении теплоизоляционных качеств гнезд птиц

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The study of thermal insulation in bird nests: justification of used parameters

В статье предложены некоторые параметры и подходы, которые можно использовать при изучении теплоизоляционных свойств гнезд птиц, в том числе и с применением тепловизионной аппаратуры. Охарактеризованы проблемы, возникающие при сравнении теплоизоляционных свойств гнезд птиц разных видов, и обсуждаются возможные пути их решения. Представлен алгоритм расчета объема и плотности сферических и чашеобразных гнезд. Дано математическое обоснование используемых формул

Ключевые слова: *гнезда птиц, теплоизоляционные свойства, тепловизионная аппаратура, стандартизация условий измерений, объем и плотность гнезд, сферические и шарообразные гнезда*

The paper suggests some parameters and approaches that can be used in the study of insulating properties in bird nests, including the use of thermal imaging equipment. The problems that arise under comparing of the insulating properties in nests of different species are described, and some possible ways of their solution are discussed. The algorithm of calculation of volume and density of sphere and cup nests is presented. The mathematical justification of the used formulas is also given

Key words: *bird nests, insulating properties, thermal imaging equipment, standardization of measurement, volume and density of nests, sphere and cup nests*

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Birds during the reproduction have to balance between active heating of eggs or chicks and constructing nests with good thermal insulation properties. In some species permanent heating compensates the absence of a 'real' nest. However, this model of behavior relates to good energy reserves and may be suitable only for comparatively big birds, e.g. waders or grouses. The majority of birds build nests, and their insulation properties let them leave nests to feed. For small birds with high intensity of metabolism this is the only chance to survive during the reproduction.

Tasks. To estimate the thermal insulation and understand how different birds maintain the balance between necessity of time for foraging and active heating of eggs and nestlings we needed to organize a comparative study of different species nests. To do that we had to solve the following tasks: 1) to standardize conditions of observations during the thermal imaging; 2) to evaluate data in relative terms; 3) to find the appropriate comparable characteristics of nests, that can describe the species-specific decision of the problem of thermal insulation. In this paper we offer some approaches and parameters used by us during the study of thermal insulation in nests.

Solution of Task 1. In order to get comparable thermal images we made infrared photos with the standardized spheroid thermostat as a heat source with precision thermal stability inside nests. We constructed the thermostat [1] based on the digital controller of temperature and supported the selected values of temperature in the range of 0.0 – 99.9 °C with accuracy of 0.1°C. In observations we used the thermal imager with appropriate infrared resolution and optical parameters [1].

In addition, we registered the weather parameters of observations, as well as wind, air temperature and humidity, which enhanced the representativeness of results. Moreover, because the artificial standardization of climatic conditions in nature is impossible, such registration allows selecting from the whole range of materials the data obtained under the similar conditions for comparative analysis.

It should be also taken into account that nest sizes vary in different species. If the research aimed for comparison of thermal conductivity of whole nests, then time of heating has to be equal in each case. Otherwise, if the research aimed for the comparison of insulation properties of nest materials, then time of heating has to vary to compensate differences in the thickness of nest walls. To determine this time for nests of different sizes we had to make some assumptions. According to Fourier's law of heat conduction [2, p. 32] for the plot of the surface area F_a and thickness δ_a with the temperature gradient from the opposite sides t_1 and t_2 the amount of heat $Q_{\tau a}$ transmitted through the surface at time τ_a will be:

$$Q_{\tau a} = (\lambda_a/\delta_a)\cdot(t_1 - t_2)\cdot F_a\cdot\tau_a.$$

The amount of heat $Q_{\tau b}$ transmitted through the surface area F_b at time τ_b under the thickness δ_b and the temperature gradient on the opposite sides of t_1 and t_2 will be:

$$Q_{\tau b} = (\lambda_b/\delta_b)\cdot(t_1 - t_2)\cdot F_b\cdot\tau_b.$$

In the theoretical comparison of two surfaces we could assume that $F_a = F_b$ and the thermal conductivity coefficients of the materials are approximately equal ($\lambda_a \approx \lambda_b$). In the comparison of plots of two surfaces we could assume that the amount of heat at each observation can be equal, too ($Q_{\tau a} = Q_{\tau b}$), consequently, the heat transfer time τ_a and τ_b in each case and the thickness of surface δ_a and δ_b will be compared as:

$$\tau_b = (\delta_b\cdot\tau_a)/\delta_a.$$

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By this formula we determined heating time of nest B (τ_b) with the wall thickness δ_b depending on heating time of the model nest (nest A) with the known wall thickness (δ_b). Thus, to obtain the comparable indicators of heat losses in different nests we adjust time of heating of each nest by the infrared emitter until the thermal imaging shot based on parameters of the nest wall thickness.

The second way to standardize thermography measurements is organizing the measurement procedure with equal distance between the nest and the lens surface in each measurements. Thus, we can summarize results of thermography and "unroll" pictures onto the plane surface (Fig. 1).

Solution of Task 2. In order to evaluate data of thermography in relative terms, we had to get the full infrared picture of a nest. Firstly, we had to determine the appropriate positions for shooting. For cup nests we made 4 pictures according to the cardinal directions. Then we summarized heat distribution pictures (Fig. 1, cup nest). For sphere nests we made 5 photos and summarized data too (Fig. 1, sphere nest).

On the second stage of analysis we compared parameters characterized heat distribution on the nest surface. We started to work with the temperature of a part of nest surface. In order to adopt it to conditions of observations we expressed it in relation to the temperature of observations. We compared residuals of the temperature of 90 %, 60 % and 30 % of the nest surface and the temperature of air.

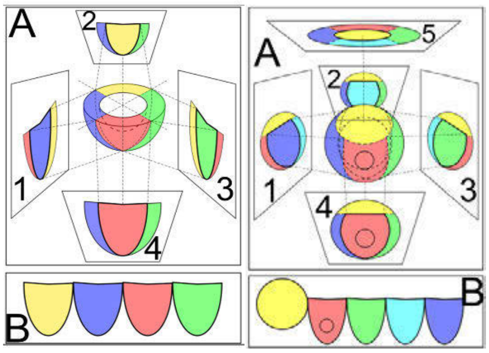

Fig. 1. A: 1 – 4 – four pictures of a nest according to the cardinal directions, 5 – top view picture of a sphere nest; B – 'unrolling' pictures onto the plane surface

Solution of Task 3. It is impossible to compare directly the insulation properties of nests in different species if nests have different sizes and configurations. However, we can estimate relative parameters universal for any nests. In search of them, by far we have stayed at three parameters: proportion of the bird mass to the nest mass, proportion of the bird mass to the nest volume, and density of the nest.

Proportion of the bird mass to the nest mass is the proportion of heat source size and weight of thermal insulation construction, and this corresponds to energy consumption of building process. *Proportion of the bird mass to the nest volume* corresponds to efficiency of building skills and it can show us whether the bird organize nest material composition effectively. *Density of the nest* relates to the building activity of a bird and indicates, whether the bird constructs a nest with or without accuracy, and depends on the material composition. We can estimate the density of the nest ρ_{nest} using the formula based on the measuring of the nest weight m_{nest} and nest volume V_{nest}:

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$$\rho_{nest} = m_{nest}/V_{nest}.$$

After the field season we measured weight of nests before and after drying them in low temperature oven when the weight becomes stable: "natural" and "dry" weight. According to these measurements we can estimate hygroscopic capacity of nests and get two density parameters – "natural" and "dry" density.

One way to determine the nest volume V_{nest} is estimation based on the nest measurements (Fig. 2). We have used this approach in our research until now. Our plans for other field seasons include analysis of nest volumes with a 3D scanner and computer modelling of nest shapes in 3D computer reality. This methodical approach could provide detailed data on the nest structure. We are going to compare the results of nest volume modelling discussed below with the results of 3D modelling with a 3D scanner. We expect to get coefficients for the nest volume definition that is more precise than we have calculated using measurements data.

Deducing of the formula for calculating of a cup nest volume:

1) estimation of the external hemisphere volume: $V_{external} = 2/3 \cdot \pi \cdot H \cdot D^2$;

2) estimation of the volume of internal hemisphere: $V_{internal} = 2/3 \cdot \pi \cdot h \cdot d^2$;

3) correction of the results as the edge of the nest is rounded (Fig. 2, A) in the axial section and made in shape of a horizontally topped torus. We have to subtract volume of the shape B (Fig. 3) from the residuals of volumes $V_{external}$ and $V_{internal}$.

Firstly, we can calculate the volume of cylinder residuals (Fig. 2):

$\Delta V_{cyl.res.} = 0.0625 \cdot \pi \cdot (D - d) \cdot D^2 - 0.0625 \cdot \pi \cdot (D - d) \cdot d^2 = 0.0625 \cdot \pi \cdot (D - d) \cdot (D^2 - d^2)$.

Secondly, we have to know the volume of horizontally topped torus (Fig. 3, A):

$$\Delta V_{top.torus} = \pi^2 \cdot (D - H + h) \cdot ((H - h)/2)^2.$$

Calculation of the volume removed from the calculation of nest wall volume:

$$V_{remove} = \Delta V_{cyl.res.} - \Delta V_{top.torus}.$$

The final formula of calculation of a cup nest volume is the following:

$$V_{nest} = V_{external} - V_{internal} - V_{remove}.$$

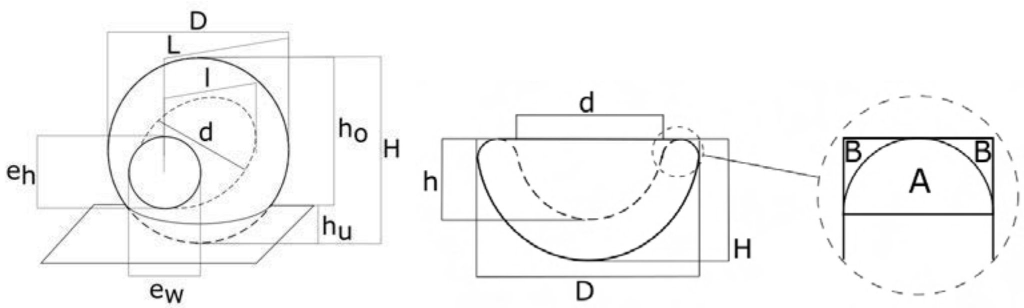

***Fig. 2.** D – external diameter, d – internal diameter, H – height, h_o – overland height, h_u – underground height, l – internal length, L – external length, e_w – entrance width, e_h – entrance height; A – horizontally topped torus of a nest edge; B – the volume that we have to remove from the calculations of the volume of the nest*

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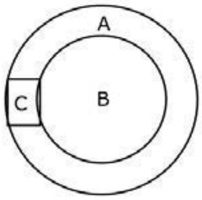

Fig. 3. Cross-sectional view of a sphere nest: A – the volume of the nest, B – the volume of the internal sphere, C – the volume of entrance cylinder

Deducing of the formula for calculating of a sphere nest volume:

1) estimation of the external sphere volume (Fig. 3, A+B): $V_{external} = 4/3\pi\cdot D\cdot H\cdot L$;

2) estimation of the volume of internal sphere (Fig. 3, B): $V_{internal} = 4/3\pi\cdot h\cdot d^2$;

3) correction of the results with entrance volume (Fig. 3, C).

The entrance volume can be found according to the following formula:

$$V_{entrance} = \pi\cdot e_w\cdot e_h\cdot(L - l).$$

The final formula of calculation of a sphere nest volume:

$$V_{nest} = V_{external} - V_{internal} - V_{entrance}.$$

The formulas listed above let us calculate nest volumes and density. These two parameters correspond to preliminary estimation of thermal insulation in nests.

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