The structural and thermal properties of avian cup-shaped nests

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"Those who admire the freedom of birds have never built a nest"

~ Anonymous

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LIST OF ABBREVIATIONS

Φ	= Heat production rate (mW)
Φ_{FAN}	= Fan heat production rate (mW)
Φ_{GLOBE}	= Globe heat production rate (mW)
λ	= Lambda, an indicator of the strength of a phylogenetic relationship
η	= Night length (h)
τ	= Time coefficient (h)
A	= Nest surface area (cm^2)
$\bar{A}$	= Geometric mean of the internal and external nest surface area (cm^2)
ΔAIC	= Akaike Information Criterion difference (phylogenetic – non-phylogenetic)
ΔAICc	= Second-order Akaike Information Criterion difference (phylogenetic – non-phylogenetic)
AIC	= Akaike Information Criterion
AICc	= Second-order Akaike Information Criterion
A_{LID}	= Surface area of the nest opening (cm^2)
A_R	= Area of the region R (cm^2)
b_0	= Egg shape parameter, representing deviation from spherical
C	= Curve in the Euclidean plane R^2
c_0	= Egg shape parameter, representing sharpness of the egg poles
d	= Nest diameter (cm)
d_0	= Egg shape parameter, representing the squareness of the egg
D_C	= Distortion from circular
D_E	= Distortion from elliptical
d_E	= External nest diameter (cm)
DEE	= Daily energy expenditure (KJ d^{-1})
d_I	= Internal nest diameter (cm)
DL	= Day length (h)
e_0	= Egg shape parameter, a general shape modifier
e	= Eccentricity
E	= Clutch size
EE	= Rate of energy expenditure (J s^{-1})
f	= Function
G	= Nest thermal conductance (mW °C^{-1})
$G_{0\%}$	= Nest conductance at 0 % water content (*i.e.* dry, mW °C^{-1})
$G_{100\%}$	= Nest conductance at 100 % water content (*i.e.* saturated, mW °C^{-1})

$G_{x\%}$	= Nest conductance at x % water content (mW °C^{-1})
G_A	= Surface-specific nest conductance (W °C^{-1} m^{-2})
$G_{A\text{-}LID}$	= Surface-specific Styrofoam lid thermal conductance (W °C^{-1} cm^{-2})
G_{LID}	= Styrofoam lid thermal conductance (mW °C^{-1})
G_{ST}	= Standardised nest conductance
G_t	= Nest conductance at time, t (mW °C^{-1})
G_{TOT}	= Nest system thermal conductance (mW °C^{-1})
h	= Nest height (cm)
h_E	= External nest height (cm)
h_I	= Internal nest height (cm)
$\%H_2O_t$	= Water content in a nest at time, t (%)
$HP_{0\%}$	= Heat production at 0 % water content (W or J s^{-1})
$HP_{x\%}$	= Heat production at measured water content, x (W or J s^{-1})
H_V	= Latent heat of vaporization, 2.259 (J mg^{-1})
I	= Current (A)
k	= Nest material thermal conductivity (mW °C^{-1} m^{-1})
K	= Blomberg *et al.*'s (2003) K-statistic, representing phylogenetic signal
L	= Egg length (cm)
LSH	= The time at which the maximum solar height occurs (h)
M	= Mean parent body mass (g)
M_C	= Clutch mass (g)
M_F	= Female body mass (g)
$\dot{M}H_2O$	= Rate of evaporation (mg s^{-1})
MH_2O_{evap}	= Mass of the evaporated water (g)
MH_2O_{satd}	= Mass of water in the nest when saturated (g)
MH_2O_t	= Mass of water in the nest at time, t (g)
M_M	= Male body mass (g)
M_N	= Nest mass (g)
M_{Ndry}	= Mass of the nest when desiccated (g)
M_{Nsatd}	= Mass of the nest when saturated (g)
M_{Nt}	= Mass of the nest at time, t (g)
NEE	= Nesting energy expenditure (KJ)
P	= Delay in maximum temperature with respect to the time of maximum solar height (h)
ρ	= Nest wall density (g cm^{-3})
PA_C	= Clutch profile area (cm^2)
PA_E	= Egg profile area (cm^2)

PCs = Principal components

R = Region on the Euclidean plane that is rotated about an axis that does not pass through that region

RH_E = Relative humidity of the CT cabinet

SA_C = Clutch surface area (cm^2)

SA_E = Egg surface area (cm^2)

SA_H = Area of the surface generated by curve, *C*, when rotated about the *x*-axis

SA_v = Area of the surface generated by curve, *C*, when rotated about the *y*-axis

SDI = Sexual size dimorphism index

ΔT = Temperature difference (°C)

t = Time elapsed (h)

T_A = Ambient temperature (°C)

T_E = External nest temperature (°C)

T_{EGG} = Egg heater surface temperature (°C)

T_I = Internal nest temperature (°C)

T_k = Effect of buoyancy (°C)

t_m = Rescaled value of x_m

T_N = Nest temperature (°C)

t_s = Sunset time (h)

V = Voltage (V)

V_B = Bird volume (mL)

V_C = Clutch volume (cm^3)

V_{CUP} = Nest cup volume (cm^3)

V_E = Egg volume (cm^3)

V_N = Nest wall volume (cm^3)

V_R = Volume of the solid generated by rotating *R* about the *x*-axis (cm^3)

V_V = Volume of the solid generating by rotating *R* about the *y*-axis (cm^3)

W = Egg width (cm)

x = Explanatory variable in a function, *f*

X = Mean nest thickness (cm)

X_B = Nest base thickness (cm)

X_W = Nest wall thickness (cm)

x_m = The distance of the centre of egg mass from the point of origin, representing deviation from an ellipse (cm)

y = Response variable in a function, *f*

z_m = Width of the egg at point x_m (cm)

ABSTRACT

Incubation in birds is energetically demanding and the energy invested to maintain egg temperature can influence the outcome of a reproductive event and therefore the lifetime reproductive success of birds. It is reasonable that heat loss can be minimised by optimising the physical structure and location of the nest. We assess the structural and thermal properties of nests across 36 species of Australian passerines, assessing variables against parent mass, egg and clutch size, once accounting for phylogenetic relationships. The surface area and volume of the nest cup increases with the surface area and volume of the clutch, as well as the size of the incubating parent. Sexual size dimorphism influences the mass and density of nests, while structural support for the parent and clutch is the primary factor driving nest thickness. A change in nest thickness with the combined mass of the parent and clutch has a direct influence on the conductance of nests, such that structurally adequate nests achieve a lower thermal conductance (higher insulation) than expected, as they increase in size. When exposed to wind or rain, the rate of heat loss from the nest increases, which is likely to have direct consequences on the energetics of the incubating parent. However, birds breeding in warm and wet conditions select materials for nest construction that have a high thermal conductivity to facilitate the nest drying process and reduce the overall cost of incubation.

DECLARATION

I, Caragh Heenan, certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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* Heenan CB, Seymour RS (2011) Structural support, not insulation, is the primary driver for avian cup-shaped nest design. *Proceedings of the Royal Society B: Biological Sciences* **278**, 2924-2929. DOI: 10.1098/rspb.2010.2798

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