Heat Loss Estimation using UAS Thermal Imagery

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Objectives

➢**WHAT**

➢Assessment of the thermal performance using IR camera for various buildings in UND campus

➢**WHY**

➢Energy audit/ certifications/ heat-loss quantification

➢**HOW**

➢U-value (or Heat Transmittance coefficient) Quantification: U-value [w/m^2-k] defines the rate of the heat that flows through one square meter of the analyzed component when the temperature on its two sides differ by one Kelvin

Influencing Parameters

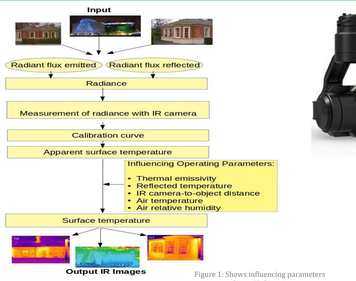
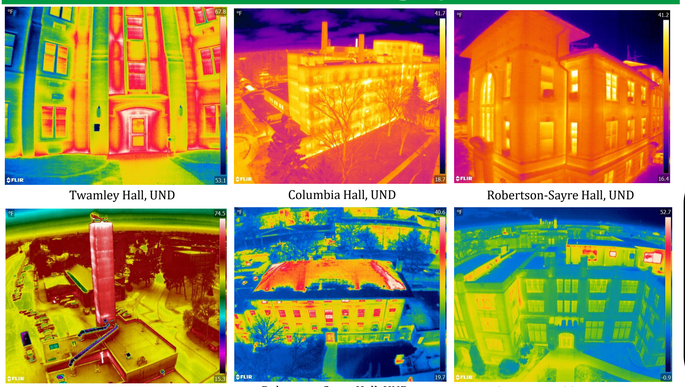


Figure 1: Shows influencing parameters for an IR Camera

Radiant Flux: is the amount of power radiated through a given area, in the form of photons or other elementary particles, typically measured in W/m2

Thermal Imagery



Twamley Hall, UND | Columbia Hall, UND | Robertson-Sayre Hall, UND

Steam Plant, UND | Robertson-Sayre Hall, UND | Education Building, UND

Figure 2:Thermal images of various buildings in the University of North Dakota (UND) campus

U-value Quantification and Prediction

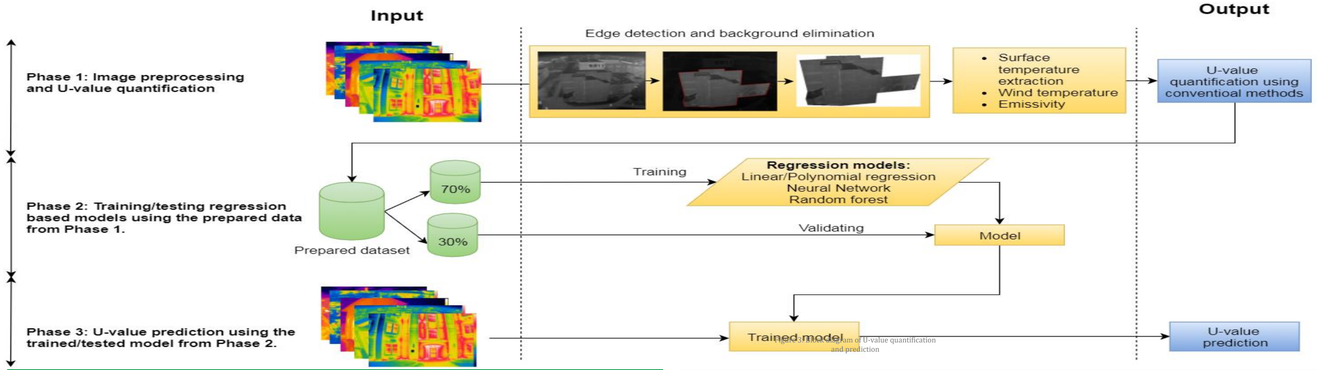


Figure 3: Overall methodology of U-value quantification and prediction

Edge Detection and Dominant Color Masking

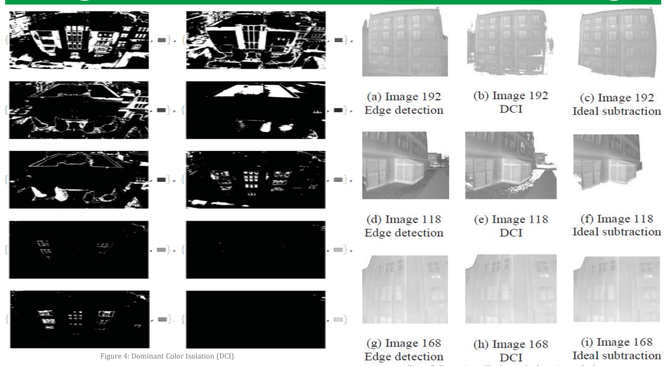


Figure 4: Dominant Color Isolation (DCI)

Figure 5: Comparison of background subtraction methods

- **Edge Detection.** Canny edge detection: Uses first order derivatives and threshold based methods to detect edges. If derivative for a pixel *p* is high, it means the corresponding pixel's value changes significantly compared to neighboring pixels [5].
- **Background Elimination** Dominant Color Isolation [6]: separates the image into dominant color channels, while masking the remaining colors. colors with a distance less than a set threshold are clustered, and clusters are separated, and masks are created by binarizing the image, with any color in the cluster appearing white, and all other colors appearing black. This results in a set of masks corresponding to the distinct color clusters. An example of this process can be seen in Figure 5

$$\text{False Positives} = \frac{\text{Pixels incorrectly removed}}{\text{Total number of pixels}} \qquad \text{False Negatives} = \frac{\text{Pixels incorrectly remain}}{\text{Total number of pixels}}$$

- The edge detection algorithm has very few false positives (FP) as compared to the number of false negatives (FN) (refer Table 3. #192). This means that the algorithm is accurate at removing pixels that should be removed, but it is not as reliable at removing pixels that it should be removing (Fig. 5). This method works best at eliminating the sky, but fails to eliminate the trees and the ground. Hence we need DCI method, where With these masks, it is possible to combine certain masks in order to eliminate background objects, while the building remains

Preprocessing

Image #	False positives (%)	False negatives (%)	Total error (%)
192	370/327680 (0.11%)	44654/327680 (13.63%)	45024/327680 (13.74%)
118	2/327680 (0%)	110132/327680 (33.61%)	110134/327680 (33.61%)
168	0/327680 (0%)	198/327680 (0.06%)	198/327680 (0.06%)

Table 3: Edge Detection

Image #	False positives (%)	False negatives (%)	Total error (%)
192	13620/327680 (4.16%)	23555/327680 (7.19%)	37175/327680 (11.34%)
118	2316/327680 (0.71%)	90030/327680 (27.48%)	92346/327680 (28.18%)
168	0/327680 (0%)	99/327680 (0%)	99/327680 (0%)

Table 2: DCI

U-value Estimation

Figure 6: Faces of Robertson-Sayre Hall used for the U-value quantification

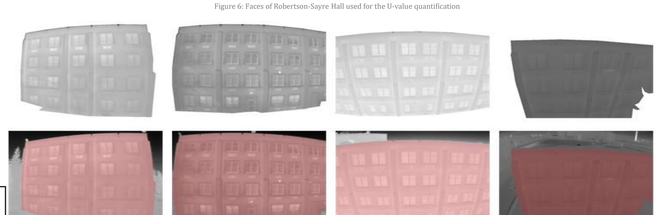


Figure 7: Faces of Robertson-Sayre Hall used for the U-value quantification

Building Name	Face 1	Face 2	Face 3	Face 4	Average
R-S Hall	0.581	4.27	-0.779	-1.837	0.55875
Twamley Hall	2.867	6.577	0.495	-2.61421	1.8311975

Table 1. U Value for different buildings

Heat Loss Equations

$$U = \frac{4\varepsilon\sigma T_m^3\left(T_w - T_{ref}\right) + h\,(T_w - T_{in})}{T_{in} - T_{out}} \quad [1]$$

$$U = \frac{4\varepsilon\sigma T_w^3\left(T_w - T_{ref}\right) + h_{in}\,(T_w - T_{in})}{T_{in} - T_{out}} \quad [2]$$

$$U = \frac{h_{out}\,(T_w - T_{out})}{T_{in} - T_{out}} \text{ with } h_{out} = 5.8 + 3.8054v \quad [3]$$

$$U = \frac{\varepsilon_v\sigma(T_w^4 - T_{out}^4) + 3.8054v(T_w - T_{out})}{T_{in} - T_{out}} \quad [4]$$

Variable	Definition
U	Overall heat transfer coefficient [W/m^{2}K]
ε, ε_v	Wall emissivity, wall spectral emissivity
σ	Stefan-Boltzmann constant [W/m^{2}K^4]
h_{in}, h_{out}, h	Indoor, outdoor, thermal convective coefficient [W/m^{2}K]
v	Wind speed [m/s]
T_{in}	Indoor air temperature [K]
T_{out}	Outdoor air temperature [K]
T_{ref}	Reflected temperature [K]
T_w	Wall temperature [K]
T_m	$\frac{T_w + T_{ref}}{2}$ [K]

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