# Evaluation of the applicability of the medium-wave infrared range for the estimation of heat losses for City of Cedar Falls, IA

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DIGITAL IMAGE PROCESSING

## INTRODUCTION

A typical house spends about 49% on heating or cooling, but more than half of this energy goes in the form of heat losses. In this regard, a survey of buildings and structures is necessary to identify and eliminate such losses, which could yield a significant positive economic effect. For such an investigation, tedious and expensive methods of manual examination using infrared thermometers were previously used. Now in connection with the rapid development of technology, it became possible to use thermal aerial photography. Most studies focus on the use of the long-wave (LWIR, 8-14 nm) infrared band, so its capabilities have been studied most fully. However, the medium-wave (MWIR, 3-5 nm) infrared band is used quite rarely. In 2010, the thermal survey of Cedar Falls in two bands was performed, which allows to compare and evaluate the measurements.

The study is of remote sensing interest because of insufficient knowledge of the possibilities of using the medium-wave range. Often, airborne thermal imagers working in two bands, but MWIR is not used in any way. In this study, we will assess the suitability of using such measurements to estimate heat loss from surfaces from various materials. With such information, consumers, such as utility companies will be able to make a more reasoned choice or refuse to use thermal imagery in this range at all depending on their needs.

## RESEARCH GOALS AND OBJECTIVES

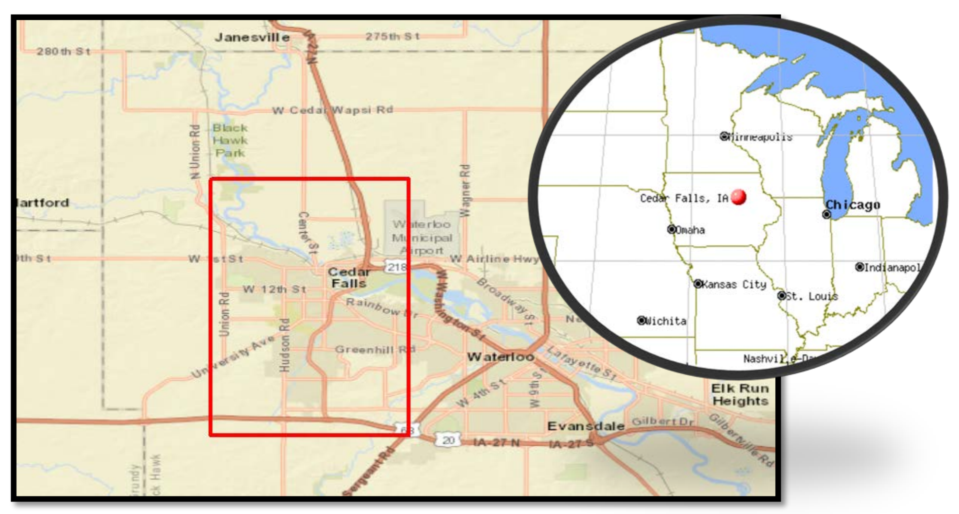
The aim of the study was the processing and subsequent comparison of temperature images in the long-wave and medium-wave range to the City of Cedar Falls. The processing was performed by converting radiance to kinetic temperature through Plank Law inversion. The comparison was conducted by a visual method using a standard deviation classification and a statistical evaluation of the temperatures obtained in the form of correlation and t-tests between the extracted temperature values from the zones belonging to different materials.

During the research we're aimed to shed the light on the following:

- How to process images without having tool calibration constants?
- Which parameters should be used in the inverted Planck law?
- What kind of visual and statistical differences are observed in the obtained images of the kinetic temperature?

## STUDY AREA, SOURCES OF THE DATA, SOFTWARE

City borders of the of Cedar Falls, IOWA. Area of the city approximately 74 sq. km., and 39 000 in population according to the 2011 population census.

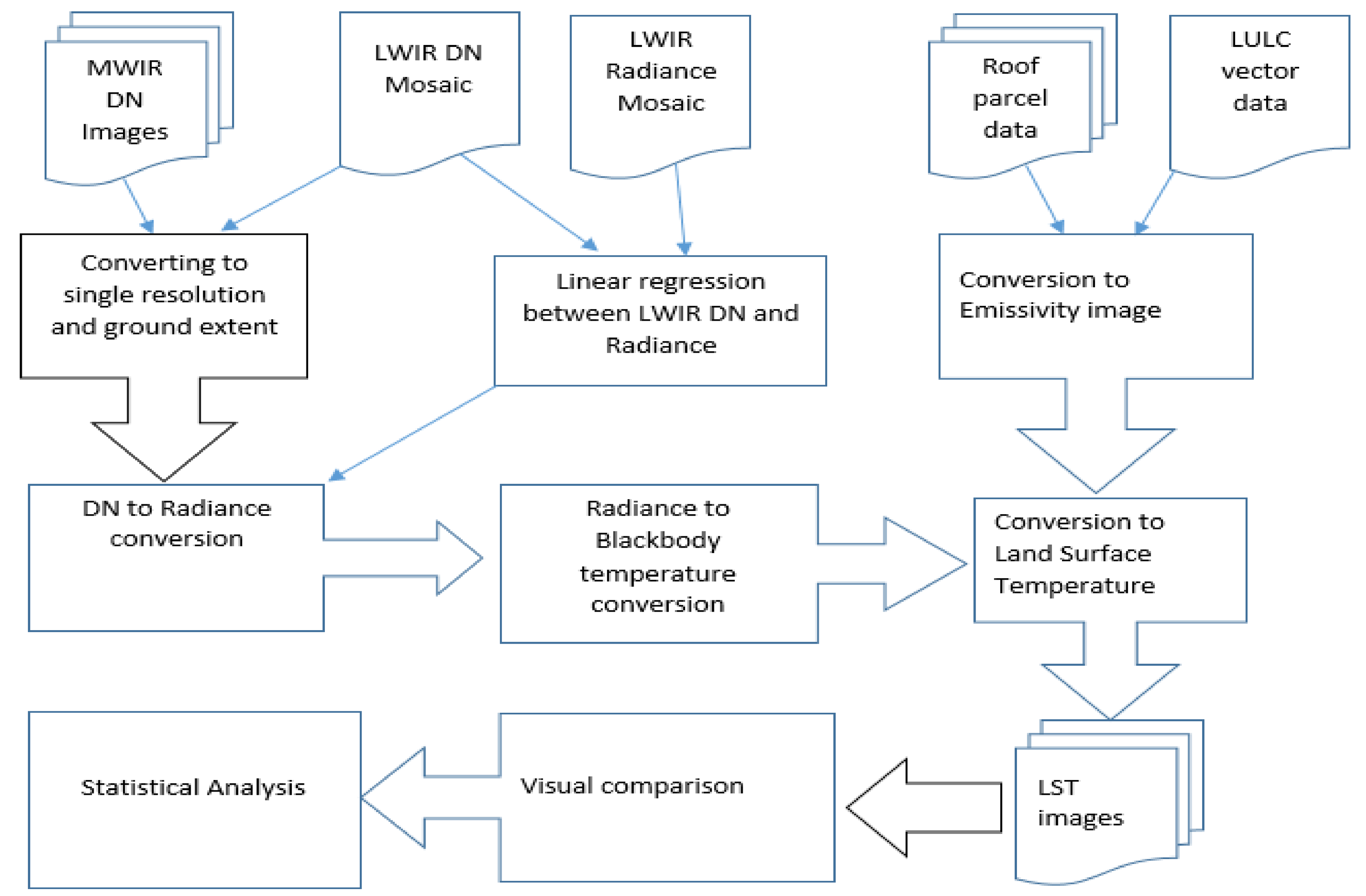


**Raster RS data:**
LWIR (8-9.2 nm) and MWIR (3-5 nm) image mosaics, 0.3 m ground resolution, from RI WASP instrument. (11/08/2010)

**Ancillary vector data:**
Roof material' map provided by Cedar Falls Utilities (2009)
Hydrography layer from OSM
Road network from IowaGISData

**Software:**
Safe Software FME 2018.0,
ESRI ArcGIS 10.5, IBM SPSS 25

## METHODOLOGY




We following the standard workflow for processing of thermal imagery from these steps:

*Geometric correction:*

Due to different spatial resolution between mosaics, they were reduced to a single spatial resolution of 0.3 m per pixel and truncated along the bounding box of the MWIR image, which was slightly smaller. Both images were ultimately brought to the same resolution 30904 * 39472 to facilitate the processing and calculation of statistics.

*Radiometric conversions:*

1) *Conversion from DN to Radiance:* due to absence of sensor calibration data and ground temperature measurements, we used linear regression to calculate the DN to radiance transition parameters. Then we used obtained slope-intercept parameters to convert from DN to Radiance

2) *Converting radiance to blackbody temperature*: We used inversion of Planck's law was used. Due to absence of image metadata the K1 and K2 coefficients were calculated assuming 4 nm central wavelength.

3) *Emissivity map creation:* we used ancillary vector data to create emissivity map. We assigned emissivity values for each type of roofs according to their material. Then we built 10-meter buffer zones along all road centerlines and assign emissivity value = 0.95 as most roads are built of concrete. We used emissivity value 0.98 for hydrography.

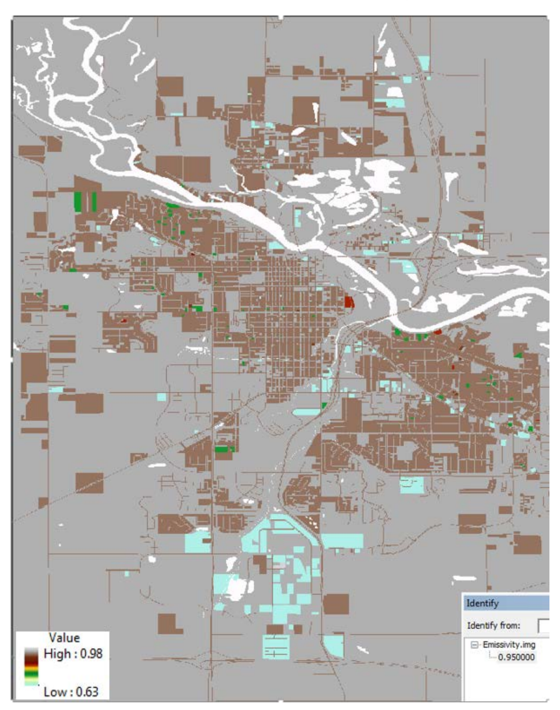
4) *Converting to Land Surface Temperature:* the Blackbody temperature raster and the emissivity map were used.

5) *Visual analysis of the differences:* resulting images were examined in ArcMap. A classification using Standard Deviation was applied and the images were inspected by visual comparison using the Swipe tool at the global and local level.

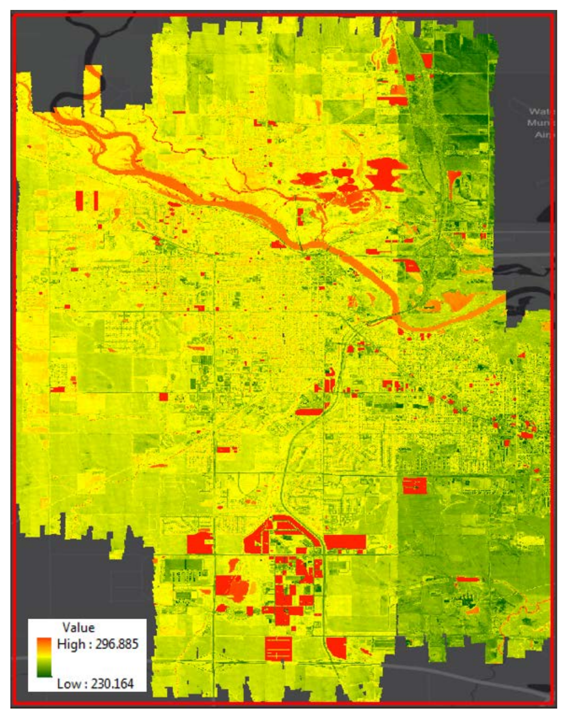
6) *Statistical analysis:* from the resulting pair of images, pairs of temperature values were extracted to calculate the total correlation. Also, pairs of temperature values were extracted separately for each type of roof material. Then we estimated correlation between sets of random samples from both images and performed t-tests.

## RESULTS

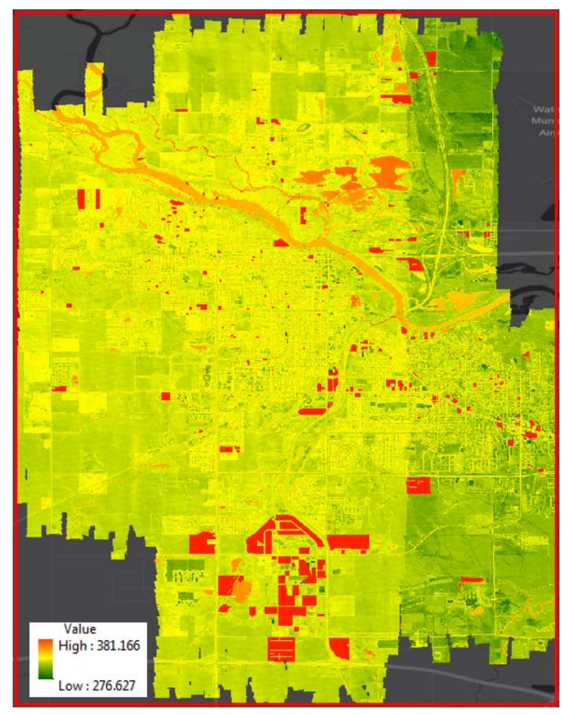
Prior to raster processing, we calculated Slope-Intercept parameters, as mentioned above. The parameters are slope 0.00007578 and intercept 0.028619. Then we calculated K1 and K2 parameters using the central wavelengths.(Table 1) Then we created the emissivity map according to the procedure discussed above.



Emissivity image



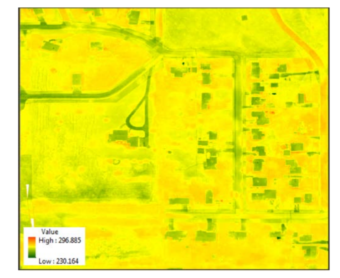
LWIR Image



MWIR Image

## RESULTS

Then we converted images to black body temperature and then applied emissivity correction. Above there are two images, displayed symbolized using standard deviation(stretched, 1 StD). Note that MWIR image appears less contrast than LWIR image and temperatures are less separable. Below the magnified part of the same image. Note the difference in the temperature of the roads which are colder on the LWIR image.



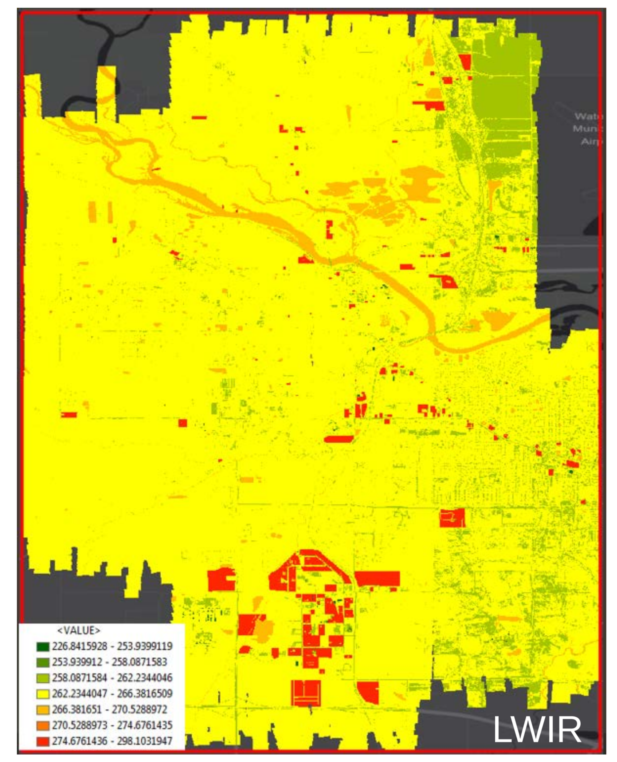
LWIR Image

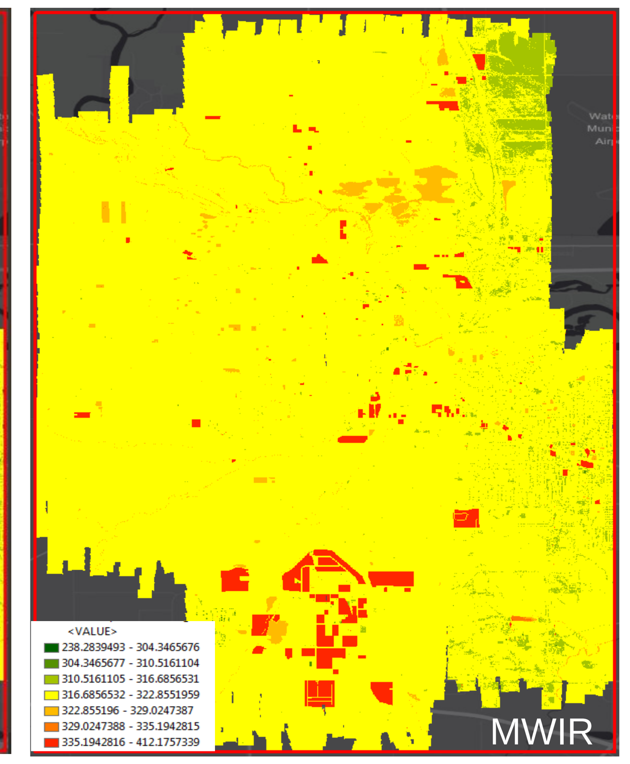
MWIR Image

**Table 1. K1-K2 values for different bands**

| Wavelength | Central wavelength | K1 | K2 |
|---|---|---|---|
| MWIR (3 – 5 µm) | 4 µm | 116312.785 | 3596.913 |
| LWIR (8 – 9.2 µm) | 8.6 µm | 2531.834 | 1672.983 |

Below you could see the same images in Standard Deviation classification, 7 classes.
Like as on previous images, tiny features are less distinctive and contrast




Having finished with visual image assessment, we performed an "independent sample"t-test between values extracted from both rasters. Values were extracted from centroids of the parcels. According to Table 2, most of the p-values are showing strong relation between values (p-value > 0.05), except measures for asphalt and wood Also we calculated correlation coefficient between 8198 sample points, evenly distributed on the images. Pearson correlation coefficient are also showing strong correlation between images

**Table 2. t-test results for different roof materials**

| | | DN | | | Blackbody | | | Emissivity corrected | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Material | Count | p-value | t-value | Correlation | p-value | t-value | corr | p-value | t-value | Correlation |
| Asphalt | 9659.00 | 0.00 | 2166.23 | 0.88 | 0.00 | -3088.38 | 0.84 | 0.00 | -3092.68 | 0.87 |
| Plywood | 391.00 | 0.00 | 352.44 | 0.70 | 0.01 | -526.86 | 0.70 | 0.02 | -379.49 | 0.81 |
| Metal | 191.00 | 0.00 | 109.07 | 0.84 | 0.02 | -174.55 | 0.84 | 0.48 | -108.79 | 0.84 |
| Tar & Gravel | 110.00 | 0.00 | 183.33 | 0.72 | 0.50 | -268.95 | 0.71 | 0.44 | -214.95 | 0.80 |
| Wood | 87.00 | 0.00 | 189.00 | 0.94 | 0.33 | -272.61 | 0.94 | 0.24 | -258.27 | 0.84 |
| Minority | 63.00 | 0.01 | 104.58 | 0.80 | 0.87 | -161.35 | 0.80 | 0.88 | -160.73 | 0.79 |
| Rubber membrane | 58.00 | 0.08 | 64.37 | 0.80 | 0.91 | -93.64 | 0.81 | 0.94 | -93.86 | 0.81 |
| Overall | 8198.00 | 0.00 | 1595.07 | 0.87 | 0.63 | -2375.90 | 0.85 | 0.00 | -665.23 | 0.98 |

## CONCLUSION

- According to visual assessment, MWIR is not performing as good as LWIR band in terms of distinction between subtle thermal differences.
- According to t-test, thermal image from MWIR band is showing best performance for temperature measurements of non-asphalt roofs.
- For asphalt and plywood roofs, the t-test results are showing no relationship between MWIR and LWIR bands.
- MWIR and LWIR thermal images showing strong correlation between each other.
- When calibration data are missing K1-K2 constants could be easily calculated based on known central band wavelength, while Brescale-Grescale values are not.