Data Analysis and Modeling for Taġiuġmiullu Nunamiullu Housing Authority
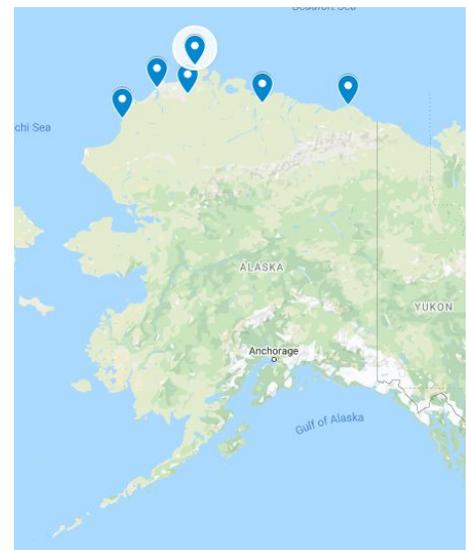***Matthew "Morgan" Moses***
Summer 2020
Composed for the Alaska Center for Energy and Power at the University of Alaska Fairbanks

In the Summer of 2020, the Alaska Center for Energy and Power (ACEP) provided an intern for the Taġiuġmiullu Nunamiullu Housing Authority (TNHA) to perform research projects on TNHA's behalf under ACEP's supervision. Two projects were initiated: 1.) the development of a data analysis tool and 2.) the creation of a thermal model of TNHA's 5th Generation Arctic Shelter..

1. Development of a data analysis tool

TNHA constructs high-efficiency homes along the Arctic Slope that are strongly optimized for the extreme-cold without sacrificing indoor air quality or aesthetic. Its newest and most sophisticated single-family unit is the Gen5 (for "5th Generation Arctic Shelter"). Twelve of these units have been constructed in Nuiqsut (5), Atqasuk (2), and Wainwright (5). As the tribally designated housing entity for Point Lay, Nuiqsut, the Naqsragmiut Tribal Council, Kaktovik, and Atqasuk, TNHA contends with large distances between construction sites and the associated high cost of transporting skilled

Figure: Areas serviced by TNHA.

trade employees to provide repairs and maintenance. To minimize waste, TNHA equips the Gen5 homes with a series of sensor relays communicating with a DeltaSol MX® (a RESOL product) which stores and processes the data. This sensor system allows TNHA to diagnose an issue with the home before ever dispatching a tradesman to service the property. Collected data are also useful for settling liability disputes between tenants and the housing authority as it can be used to determine if a tenant has inappropriately tampered with the utility settings.

However, there is a significant hurdle to accessing the data processed by the RESOL system. Despite the resolution of the data (processed at one-minute time intervals), the module exports each

individual day's worth of data as a single file of tab separated values. This becomes a problem because the visualization software packaged with the RESOL system can only process a single file at a time, meaning that it can only visualize a single day's worth of information at a time. With the current system, TNHA must parse each individual day's worth of data to find the root cause of a tenant's issue. This process is time consuming and precipitated TNHA's first project, a new data analysis tool.

TNHA needed a tool to visualize large amounts of data from the RESOL system in a convenient way that requires very little input from the user. These data also needed to be exported to a Graphical User Interface (GUI) that is convenient and intuitive to navigate. MatLab® was employed as the development platform for this project for several reasons:

- It is extremely well optimized to read, manipulate, and visualize data of this type with built-in support for a powerful GUI that is easy to navigate and understand.
- MatLab® code is modular and easy to adapt to new needs or updates to the RESOL system's firmware.

The tool works by sequentially reading a list of .txt files into a struct. The selection of the files is prompted from a GUI that appears when the user runs the script. It then parses the struct for the existence of certain fields and reads each column of data into a vector, appending the next day's data onto the previous vector. For runtime efficiency, the data is read by day rather than by column so that each member of the struct is accessed only once. As much as is possible, the script is executed by linear commands to improve runtime. As a consequence, large blocks of code are very similar to one another and anyone attempting to

```
if (myIsField (Data(1), 'Drehzahl_Relais_2') == 1)

    Pump2=Data(1).Drehzahl_Relais_2';

        for i=2:length(FileName)

            temporary=Data(i).Drehzahl_Relais_2';
            Pump2 =[Pump2 temporary];

        end

    consecutive=0;
    PumpDuration2=zeros(1,length(Pump2));

    for i=1:length(Pump2)

        if Pump2(i)~= 0
if (myIsField (Data(1), 'Drehzahl_Relais_3') == 1)

    Pump3=Data(1).Drehzahl_Relais_3';

        for i=2:length(FileName)

            temporary=Data(i).Drehzahl_Relais_3';
            Pump3 =[Pump3 temporary];

        end

    consecutive=0;
    PumpDuration3=zeros(1,length(Pump3));

    for i=1:length(Pump3)

        if Pump3(i)~= 0
            consecutive = consecutive +1;
            PumpDuration3(i)= consecutive;

        else
            consecutive = 0;
        end
    end
```

Figure : Portions of the code are almost indistinguishable, and users must be careful when modifying them

modify this code should be careful to ensure that they are specific about which vectors they want to call as these similarities can make different portions of the code difficult to distinguish from one another.

The result of the script is an output window that sorts the data by relevant type (temperature, pump runtimes, irradiation, and relays). Individual plots can be toggled to display the sensor output at that position
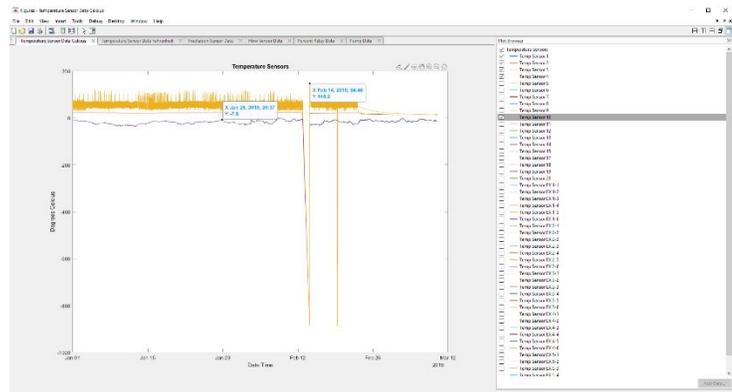

Figure : Sensor data is displayed in an easy-to-navigate interface

as well as the accompanying date-time stamp. The script takes approximately five-minutes to execute for a year's worth of data and should significantly reduce the amount of time it takes TNHA to parse sensor data. TNHA is currently implementing the script and should be able to provide feedback and requests for revisions.

2.) Construction of a thermal model of TNHA's 5th Generative Arctic Shelter

The second project was to construct a thermal model of TNHA's 5th Generation Arctic Shelter using the Transient System Simulation Tool (TRNSYS®). This project was particularly challenging for several reasons:

- TNHA's intern had no prior experience working with TRNSYS® or SketchUp®. To facilitate their use, specialized training had to be undertaken (McDowell, 2020; S.A. Klein, et al., 2018).
- The 5th generation home has undergone a significant amount of design by iteration with each subsequent revision improving upon the last. As such, the current incarnation of the structure is different from what is presented in TNHA's provided documentation. A great deal of disambiguation had to be performed to model the systems accurately.
- The Arctic home presents a sophisticated thermal model. With many components and multiple interdependent thermal systems, the house requires extreme care in how it is modeled.

The first milestone of the project was to accurately recreate the geometries of the 5th generation shelter. This was accomplished by using SketchUp® and its fre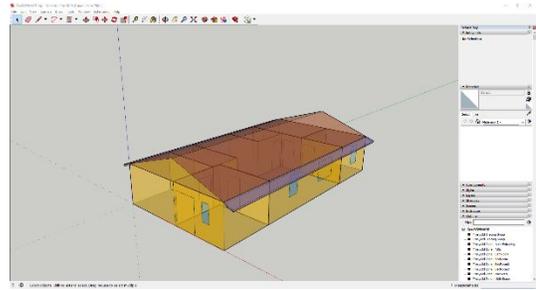e plugin TRNSYS3D. Two versions of the building were made: a simplified single-zone model for prototyping the loops and components of the simulation studio, and a more

Figure :TRNSYS3D is an open source plugin developed by the National Renewable Energy Laboratory

sophisticated multi-zone model to more accurately model the building and the interactions between the rooms.

Next, the model was imported into TRNBUILD®, a subcomponent of TRNSYS® that allows the programmer to specify the composition and thermal properties of the surfaces of the building while adding ventilation, idealized heating and cooling, daylight models, and defining convection properties of the interior and immediate exterior. The difficulty of this process was eased extensively by access to the TESS libraries included in ACEP's license for TRNSYS. Many building materials were already programmed as predefined objects in these libraries and provided references for defining thermal properties of the materials used in the building.

The building's thermal systems were then modeled in the TRNSYS® simulation studio as three separate thermal loops:

Figure : The home's heat is tracked through three color-coded loops in the TRNSYS simulation studio

- The red loop tracks the heat provided by the diesel-fired backup heating supply.
- The purple loop tracks the heat provided to the domestic hot water (DHW) system from the array of solar-thermal panels on the roof of the home.
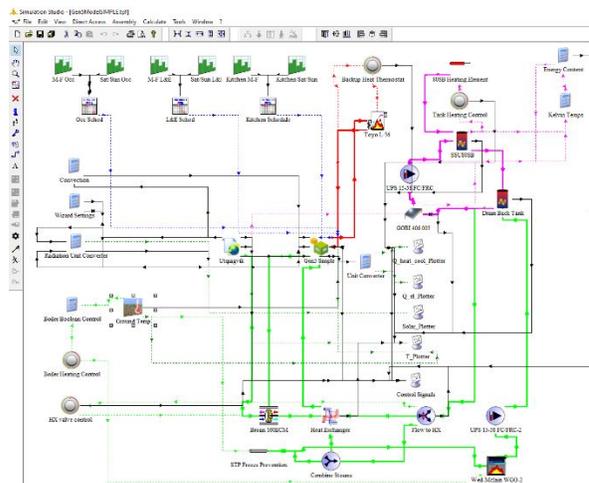
- The green loop tracks the heat retained in the house from the heat recovery ventilator (HRV) as well as the heat gathered from the polypropylene glycol passing through the fan-hood heat exchanger. The polypropylene glycol is originally heated by a diesel-fired boiler for the purpose of providing freeze-protection for the home's wastewater treatment tank.
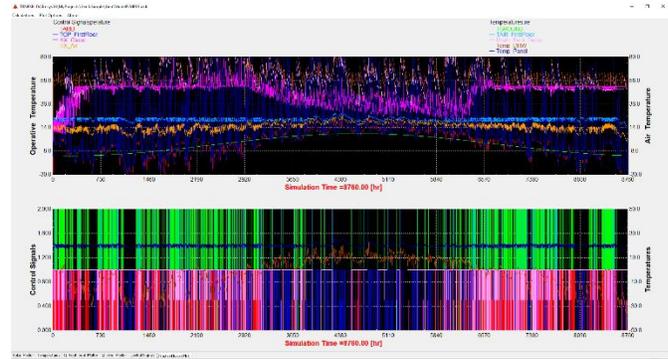

Figure : Simulating temperatures and control signals for a weather-normalized year

Once constructed, the three loops were coupled to models for weather and ground temperature. This coupling allowed TRNSYS® to simulate the environmental effects and heating requirements of the structure for an entire year using fifteen years of weather data for the chosen location. The next step was to determine if the model is a reasonable representation of reality. Sensor data from TNHA was used to estimate solar energy gains by using the following equation at every time step where the boolean pump control returned "true":

$$Q = m * Cp * \Box \text{T}$$

This same process was applied to the inlet and outlet temperatures of the panel provided by the TRNSYS model and the two results were compared. While the irradiation values of the model and sensor data align quite closely, the
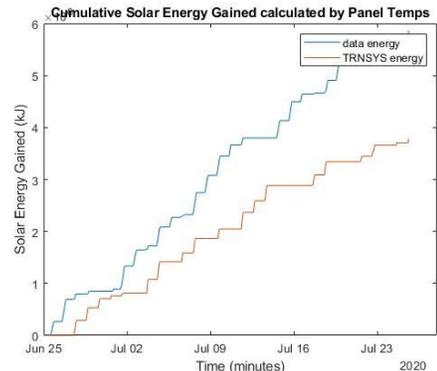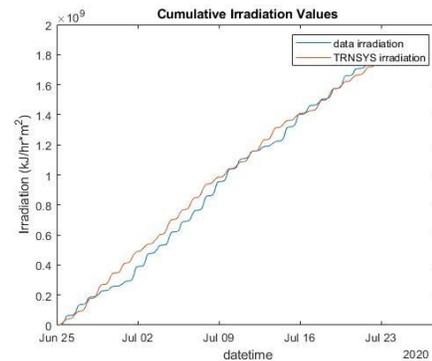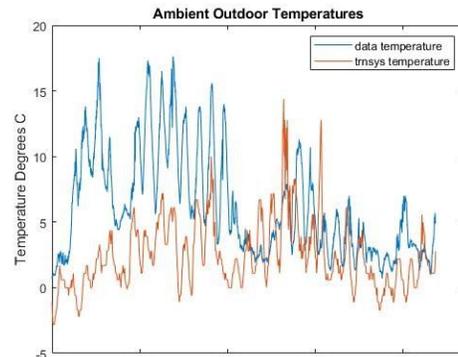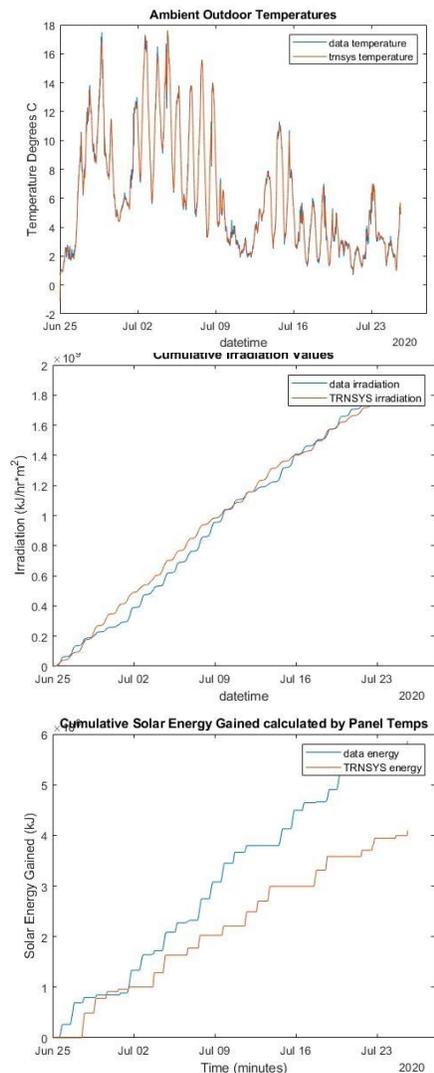

Figure: Comparison of energy gains from TRNSYS and sensor data.

model experiences much colder outdoor temperatures for the first half of the month. The predicted solar energy gain in the model is approximately $2x10^6$kJ lower than the idealized energy gain derived from TNHA's sensors. The next step is to determine if this discrepancy is due to the difference between the sensor data and TRNSYS's weather file. A custom weather file was constructed as an input for TRNSYS and the simulation was repeated. The impact of the difference in outdoor temperatures was very small, and the outputs from the model were still significantly lower than the idealized energy gains calculated from the sensor data.

The value of the TRNSYS model varies depending on who is using it. If proven to be a valid representation, TNHA could potentially use the model to prototype intended design changes to its arctic shelter by forecasting the impact of these design decisions without physical construction or the time required to gather real-world data. Changing the thermal envelope would require a new TRNSYS3D model to be constructed in SketchUp® and moved to TRNBUILD®. This would require variables such as ventilation, construction materials, and air change rates to be redeclared by hand and should only be attempted by a skilled TRNSYS user. Implementing new systems within the existing envelope is much more accessible as components can be placed directly into the simulation studio and establishing connections between them is much more logical. Evaluating the existing home and the existing systems in different locations is the easiest change to make. The simulation studio contains a location component that can be updated by clicking into its properties and changing the weather file under the "external files" tab.

Figure: Comparison of energy gains from TRNSYS and sensor data using a modified weather file as an input to TRNSYS.

Academics could find the model useful for scholarly pursuits related to cold weather housing as it generates outputs extremely quickly and can simulate very large amounts of data on demand without the difficult task of finding a large pool of subjects for study. Real world homes owned by cooperative tenants that can provide accurate, granular data are likely to be uncommon especially given the low population density of rural Alaska.

The new partnership with TNHA shows promise. The utility has certainly received a tool that is immediately useful and both parties have collaborated on a model that may open inroads to further partnership and scientific inquiry. The limited availability of automated data uploads and cost of travel greatly limits the pool of sensor data that TNHA has available to share. In future collaborations, significant notice should be given to TNHA to accumulate a substantial pool of sensor data for analysis, or in-person help should be provided for data collection.

Works Cited:

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Klein, S.A., et al. (2020). TRNSYS 18 [Help Documentation]. Madison, WI: Thermal Energy System Specialists.

McDowell, A. [EnergyAE]. (2020, 04, 01). *Learn TRNSYS* [Video Series]. Udemy. https://www.udemy.com/course/learn-trnsys/