100% Solar heated house with attic heat store for Ottawa, Ontario

Calculation of heat loss and solar collector area

This is a MathCAD 8 file.

David Delaney, Ottawa, November 21, 2004

The house is a bungalow (one storey) on a well-insulated slab. The slab is raised four or five feet above grade to allow for a tall solar air heater on the south facade of the building. The air heater operates entirely by natural convection, charging a thermal mass situated above it. Since the only exchange of air between the air heater and the rest of the house occurs through the top of the air heater, all air exchange stops when the air heater becomes cold. The thermal mass is located in an overhead attic heat store, about four feet in vertical extent, and covering the whole of the habitable space below. The reminder of the house is assumed to have no thermal mass. The thermal mass in the attic heat store consists of a one foot (0.3 m) thick layer of 1-1/2" to 2-1/2" stones (load: 100 lbf/ft^2, 4800 n/m^2) supported on wire mesh two feet above the floor of the attic heat store. There is a one foot space between the top of the stones and the ceiling of the attic heat store. A thermostatically controlled ducted fan draws hot air from the top of the attic heat store into the living space below. A *flow organiser* permits the coolest air in the attic heat store to pass through the flow of hot air rising from the air heater so that the cool air may fall through the air heater against the glazing. For details of the thermal scheme of the house see http://geocities.com/davidmdelaney/thermal-cs/thermal-crawl-space-1.html. For details of the flow organiser see http://geocities.com/davidmdelaney/flow-organiser/flow-organiser.html.

Units:

$F \equiv \frac{5}{9} K$ $\quad Btu \equiv 1054\ J$ $\quad C \equiv K$ $\quad MMBtu \equiv 10^6\ Btu$

$kJ \equiv 1000\ J$ $\quad kW \equiv 1000\ W$ $\quad kWh \equiv 3.6 \cdot 10^6\ J$ $\quad GJ \equiv 10^9\ J$ $\quad kBtu \equiv 1000\ Btu$

$R \equiv 1\ \frac{ft^2 \cdot hr \cdot F}{Btu}$ $\quad RSI \equiv 1 \cdot \frac{m^2 \cdot K}{W}$ $\quad RSI = 5.673 \circ R$ $\quad R = 0.1763 \circ RSI$

Temperatures:

$Th := 70\ F$	$Th - 32 \cdot F = 21.1\,{}^{\circ}C$	Temperature of the habitable space of the house
$Tahs := 100\ F$	$Tahs - 32\ F = 37.8\,{}^{\circ}C$	Average temperature of attic heat store
$Ta := 14\ F$	$Ta - 32\ F = -10\,{}^{\circ}C$	Ambient (outdoor) air temperature. Used only to model temperature decline when there is no sun..
$Tg \equiv 50\ F$	$Tg - 32\ F = 10\,{}^{\circ}C$	Temperature of the ground below the house.
$Tbase \equiv 64.4\ F$	$Tbase - 32\ F = 18\,{}^{\circ}C$	Temperature wrt which degree days are measured

Although MathCAD converts automatically between dimensionally consistent units known to it, it cannot do unit conversions that involve addition. So although it converts very well between Fahrenheit and Celsius temperature *differences,* it cannot convert between temperatures. I have chosen to make Fahrenheit the scale in which *temperatures* are entered. I enter *temperature difference data* in whatever scale I obtained the data. I enter degree-days data, for example, in Celsius.

Miscellaneous parameters:

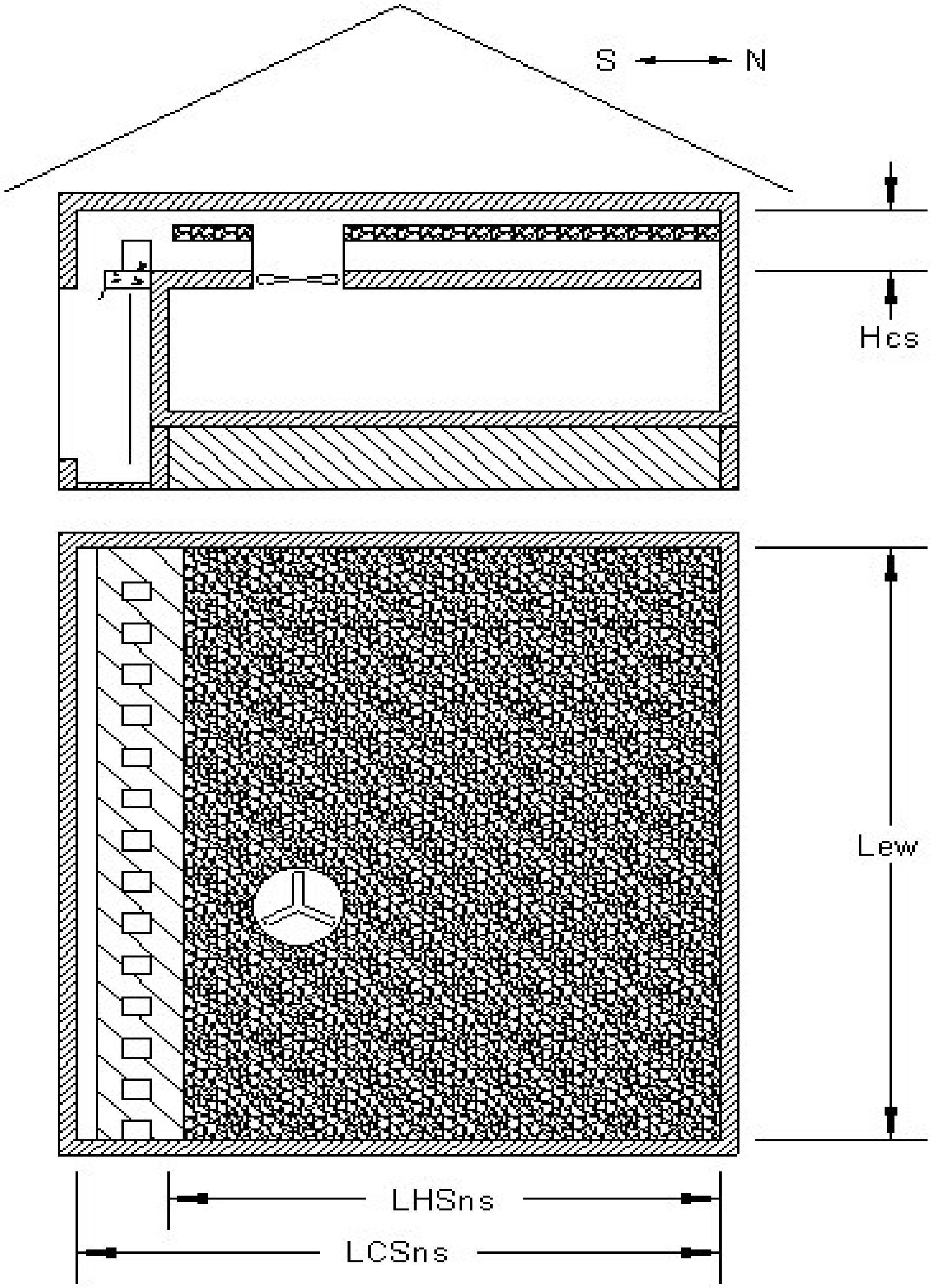
$NumberOfPersons \equiv 3$	In continuous residence
$baseNonSolarHeatGain := 200\ W$	Human body heat.
$electricityUsageHeatGain := 400\ W$	Electric lights, toaster, microwave, computer, TV, radio, CD player, DVD player, VHS, electric stovetop and oven

$$nonSolarHeatGain := baseNonSolarHeatGain + electricityUsageHeatGain$$

$$nonSolarHeatGain = 600\ W$$

$thermalCapacity := 22000\ \frac{Btu}{F}$	Thermal capacity of the the attic heat store. 22,000 Btu/F is the thermal capacity of 11 tons water, or 10 tonnes water, or 55 tons of stone, or 50 tonnes of stone

$$thermalCapacity = 11.6\,{}^{\circ}\frac{kWh}{C}$$


S
N
Hcs
Lew
LHSns
LCSns

Dimensions:

$\mathrm{Lew} \equiv 40 \cdot \mathrm{ft}$ $\mathrm{Lew} = 12.2\ \mathrm{m}$ The east-west length of the interior of the house

$\mathrm{LHSns} \equiv 30 \cdot \mathrm{ft}$ $\mathrm{LHSns} = 9.1\ \mathrm{m}$ The north south length of the habitable space

$\mathrm{LAHSns} \equiv 35 \cdot \mathrm{ft}$ $\mathrm{LAHSns} = 10.7\ \mathrm{m}$ The north south length of the attic heat store

$\mathrm{Hahs} \equiv 4 \cdot \mathrm{ft}$ $\mathrm{Hahs} = 1.2\ \mathrm{m}$ The height of the attic heat store

$\mathrm{Hhs} \equiv 8 \cdot \mathrm{ft}$ $\mathrm{Hhs} = 2.4\ \mathrm{m}$ The height of the habitable space

R-values:

$\mathrm{Rr} \equiv 100 \cdot \mathrm{R}$ $\mathrm{Rr} = 17.6 \circ \mathrm{RSI}$ Roof

$\mathrm{Rwalls} \equiv 50 \cdot \mathrm{R}$ $\mathrm{Rwalls} = 8.8 \circ \mathrm{RSI}$ Walls of the habitable space

$\mathrm{Rf} \equiv 20 \cdot \mathrm{R}$ $\mathrm{Rf} = 3.5 \circ \mathrm{RSI}$ Floor of habitable space

$\mathrm{Rwin} \equiv 4\ \mathrm{R}$ $\mathrm{Rwin} = 0.7 \circ \mathrm{RSI}$ Windows

$\mathrm{Rahs\_wall\_inc} \equiv 7\ \mathrm{R}$ $\mathrm{Rahs\_wall\_inc} = 1.2 \circ \mathrm{RSI}$ attic heat store wall increment

Solar collector (air heater) data:

$\mathrm{NumberOfGlazingLayers} \equiv 1$ Not set up to change this.

$\mathrm{Rah\_glazing} := \mathrm{NumberOfGlazingLayers} \cdot \mathrm{R}$ R-value of the air heater glazing

$\mathrm{Rah\_glazing} = 1 \circ \mathrm{R}$ $\mathrm{Rah\_glazing} = 0.176 \circ \mathrm{RSI}$ Not currently used

$\mathrm{TransmissionCoefficient} \equiv 0.85^{\mathrm{NumberOfGlazingLayers}}$ Proportion of incident energy that gets through the glazing.

$\mathrm{TransmissionCoefficient} = 0.85$

$\mathrm{EnergyRetentionCoefficient} \equiv 0.6$ Guess. Proportion of energy that gets through the glazing that is transferred into the attic heat store.

$\mathrm{airHeaterEfficiency} \equiv \mathrm{TransmissionCoefficient} \cdot \mathrm{EnergyRetentionCoefficient}$

$\mathrm{airHeaterEfficiency} = 0.51$ Proportion of solar radiation energy that falls on the air heater glazing that winds up in the attic heat store.

Window data:

$\text{WindowFractionOfFloor} \equiv 0.1$

$\text{Ws} \equiv \frac{1}{4} \cdot \text{WindowFractionOfFloor} \cdot \text{Lew} \cdot \text{LHSns}$ Area of south windows

$\text{Ws} = 30 \circ \text{ft}^2$ $\text{Ws} = 2.8\ \text{m}^2$

$\text{Wewn} \equiv \frac{3}{4} \cdot \text{WindowFractionOfFloor} \cdot \text{Lew} \cdot \text{LHSns}$ Area of east west and north windows

$\text{Wewn} = 90 \circ \text{ft}^2$ $\text{Wewn} = 8.4\ \text{m}^2$

Conductances:

East west and north windows: $\text{Gwin\_ewn} \equiv \frac{\text{Wewn}}{\text{Rwin}}$ $\text{Gwin\_ewn} = 22.5 \circ \frac{\text{Btu}}{\text{hr} \cdot \text{F}}$ $\text{Gwin\_ewn} = 11.9 \circ \frac{\text{W}}{\text{C}}$

South windows $\text{Gwin\_s} \equiv \frac{\text{Ws}}{\text{Rwin}}$ $\text{Gwin\_s} = 7.5 \circ \frac{\text{Btu}}{\text{hr} \cdot \text{F}}$ $\text{Gwin\_s} = 4 \circ \frac{\text{W}}{\text{C}}$

Attic heat store $\text{Gcs} \equiv \frac{(2 \cdot \text{Lew} + 2 \cdot \text{LAHSns}) \cdot \text{Hahs}}{\text{Rwalls} + \text{Rahs\_wall\_inc}} + \frac{\text{Lew} \cdot \text{LAHSns}}{\text{Rr}}$

$\text{Gcs} = 24.5 \circ \frac{\text{Btu}}{\text{hr} \cdot \text{F}}$ $\text{Gcs} = 12.9 \circ \frac{\text{W}}{\text{C}}$

We treat the floor of the attic heat store as if its conductance is 0, since the sum of all energy flows to the habitable space from the attic heat store is exactly equal to the heat losses to the exterior from the habitable space.

East west and north walls: $\text{Gewn\_walls} \equiv \frac{(\text{Lew} + 2 \cdot \text{LHSns}) \cdot \text{Hhs} - \text{Wewn}}{\text{Rwalls}}$

South wall $\text{Gs\_wall} \equiv \frac{\text{Lew} \cdot \text{Hhs} - \text{Ws}}{\text{Rwalls}}$

Floor $\text{Gfloor} \equiv \frac{\text{Lew} \cdot \text{LHSns}}{\text{Rf}}$

Ventilation load:

Use a well known crude approximation for the enthalpy change of air: "To raise the temperature of one cubic foot of air by one degree Fahrenheit in one minute requires a heating power of one Btu per hour".

$$\mathrm{EnthalpyChangeApprox} \equiv \frac{1}{60} \frac{\mathrm{Btu}}{\mathrm{ft}^3 \cdot \mathrm{F}}$$

Use ASHRAE 62 outdoor air requirement

$$\mathrm{ASHRAE\_62\_requirement\_per\_person} \equiv 15 \frac{\mathrm{ft}^3}{\mathrm{min}}$$

$$\mathrm{NewAirVolumeRate} := \mathrm{NumberOfPersons} \cdot \mathrm{ASHRAE\_62\_requirement\_per\_person}$$

$$\mathrm{NewAirLossPerDegree} := \mathrm{EnthalpyChangeApprox} \cdot \mathrm{NewAirVolumeRate}$$

$$\mathrm{NewAirLossPerDegree} = 45 \circ \frac{\mathrm{Btu}}{\mathrm{hr} \cdot \mathrm{F}} \qquad \mathrm{NewAirLossPerDegree} = 23.7 \circ \frac{\mathrm{W}}{\mathrm{C}}$$

Degree days analysis:

"EL" = "energy loss"

$$\text{EL\_air}(\text{days},\text{ddays}) := \text{NewAirLossPerDegree}\cdot((\text{Th}-\text{Tbase})\cdot\text{days}+\text{ddays})\cdot\text{day}$$

$$\text{EL\_air}(31, 824\ \text{C}) = 1.9\cdot 10^{9}\ \text{J}$$

$$\text{EL\_ewn}(\text{days},\text{ddays}) := \begin{pmatrix}\text{Gewn\_walls}\ \ldots\\ +\ \text{Gwin\_ewn}\end{pmatrix}\cdot((\text{Th}-\text{Tbase})\cdot\text{days}+\text{ddays})\cdot\text{day}$$

$$\text{EL\_ewn}(31, 824\ \text{C}) = 1.5\cdot 10^{9}\ \text{J}$$

$$\text{EL\_s}(\text{days},\text{ddays}) := \begin{pmatrix}\text{Gs\_wall}\ \ldots\\ +\ \text{Gwin\_s}\end{pmatrix}\cdot((\text{Th}-\text{Tbase})\cdot\text{days}+\text{ddays})\cdot\text{day}\cdot\frac{3}{4}$$

South wall only loses energy for 3/4 day

$$\text{EL\_s}(31, 824\ \text{C}) = 4.2\cdot 10^{8}\ \text{J}$$

$$\text{EL\_tcs}(\text{days},\text{ddays}) := \text{Gcs}\cdot((\text{Tahs}-\text{Tbase})\cdot\text{days}+\text{ddays})\cdot\text{day}$$

$$\text{EL\_tcs}(31, 824\ \text{C}) = 1.6\cdot 10^{9}\ \text{J}$$

$$\text{EL\_floor}(\text{days},\text{ddays}) := \text{Gfloor}\cdot(\text{Th}-\text{Tg})\cdot\text{days}\cdot\text{day}$$

$$\text{EL\_floor}(31, 824\ \text{C}) = 9.4\cdot 10^{8}\ \text{J}$$

$$\text{EL}(\text{days},\text{ddays}) := \begin{bmatrix}\text{EL\_air}(\text{days},\text{ddays})\ \ldots\\ +\ \text{EL\_ewn}(\text{days},\text{ddays})\ \ldots\\ +\ \frac{3}{4}\cdot\text{EL\_s}(\text{days},\text{ddays})\ \ldots\\ +\ \text{EL\_tcs}(\text{days},\text{ddays})\ \ldots\\ +\ \text{EL\_floor}(\text{days},\text{ddays})\ \ldots\\ +\ (-\,\text{nonSolarHeatGain}\cdot 24\ \text{hr}\cdot\text{days})\end{bmatrix}$$

No loss through south wall for 1/4 of each day

$$\text{Months} := (\text{"Oct"}\quad \text{"Nov"}\quad \text{"Dec"}\quad \text{"Jan"}\quad \text{"Feb"}\quad \text{"Mar"}\quad \text{"Apr"})$$

$$\text{mnthDays} := (31\quad 30\quad 31\quad 31\quad 31\quad 31\quad 30)^{T}$$

Solar radiation data (HDdays, irradiancePerDay) from NASA meteorology site, http://eosweb.larc.nasa.gov/sse/, for location 45.316N, 75.666W, (Ottawa, Ontario).

Heating degree days: $\text{HDdaysOttawa} \equiv (327\quad 536\quad 824\quad 870\quad 751\quad 619\quad 341)^{T}\ \text{C}$

Parameters for tilted

Parameters for tilted solar panels: Radiation on equator-pointed tilted surfaces / RETScreen method, Tilt 90 row:

$$\mathrm{irradiancePerDayOttawa} := \left(2.38 \quad 1.87 \quad 2.16 \quad 2.96 \quad 3.54 \quad 3.41 \quad 2.85\right)^{T} \frac{\mathrm{kWh}}{\mathrm{m}^2}$$

$$\mathrm{irradiancePerDayOttawa}_2 = 2.2 \circ \frac{\mathrm{kWh}}{\mathrm{m}^2}$$

$$\mathrm{ELm}(\mathrm{mnth}) := \mathrm{EL}\left(\mathrm{mnthDays}_{\mathrm{mnth}}, \mathrm{HDdaysOttawa}_{\mathrm{mnth}}\right)$$

Oct	$\mathrm{ELm}(0) = 2 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(0) = 2.1 \circ \mathrm{GJ}$	$\mathrm{ELm}(0) = 584 \circ \mathrm{kWh}$
Nov	$\mathrm{ELm}(1) = 3 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(1) = 3.2 \circ \mathrm{GJ}$	$\mathrm{ELm}(1) = 881 \circ \mathrm{kWh}$
Dec	$\mathrm{ELm}(2) = 4.4 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(2) = 4.7 \circ \mathrm{GJ}$	$\mathrm{ELm}(2) = 1.3 \cdot 10^3 \circ \mathrm{kWh}$
Jan	$\mathrm{ELm}(3) = 4.7 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(3) = 4.9 \circ \mathrm{GJ}$	$\mathrm{ELm}(3) = 1.4 \cdot 10^3 \circ \mathrm{kWh}$
Feb	$\mathrm{ELm}(4) = 4.1 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(4) = 4.3 \circ \mathrm{GJ}$	$\mathrm{ELm}(4) = 1.19 \cdot 10^3 \circ \mathrm{kWh}$
Mar	$\mathrm{ELm}(5) = 3.4 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(5) = 3.6 \circ \mathrm{GJ}$	$\mathrm{ELm}(5) = 1 \cdot 10^3 \circ \mathrm{kWh}$
Apr	$\mathrm{ELm}(6) = 2.1 \circ \mathrm{MMBtu}$	$\mathrm{ELm}(6) = 2.2 \circ \mathrm{GJ}$	$\mathrm{ELm}(6) = 600.7 \circ \mathrm{kWh}$

Required size of vertical solar aperature:

$$\mathrm{airHeaterEfficiency} = 0.51$$

$$\mathrm{SolarArea}(\mathrm{mnth}) := \frac{\mathrm{ELm}(\mathrm{mnth})}{\mathrm{airHeaterEfficiency} \cdot \mathrm{mnthDays}_{\mathrm{mnth}} \cdot \mathrm{irradiancePerDayOttawa}_{\mathrm{mnth}}}$$

Oct	$\mathrm{SolarArea}(0) = 167.1 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(0) = 15.5 \circ \mathrm{m}^2$
Nov	$\mathrm{SolarArea}(1) = 331.5 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(1) = 30.8\ \mathrm{m}^2$
Dec	$\mathrm{SolarArea}(2) = 409.5 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(2) = 38\ \mathrm{m}^2$
Jan	$\mathrm{SolarArea}(3) = 314 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(3) = 29.2\ \mathrm{m}^2$
Feb	$\mathrm{SolarArea}(4) = 229.6 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(4) = 21.3\ \mathrm{m}^2$
Mar	$\mathrm{SolarArea}(5) = 200.5 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(5) = 18.6\ \mathrm{m}^2$
Apr	$\mathrm{SolarArea}(6) = 148.3 \circ \mathrm{ft}^2$	$\mathrm{SolarArea}(6) = 13.8\ \mathrm{m}^2$

Temperature decline with no sun:

Calculate the temperature of the attic heat store assuming only a small amount of miscellaneous non-solar power input.

$\mathrm{clock}(t) := t - 24 \cdot \mathrm{floor}\left(\frac{t}{24}\right)$

t = hours elapsed with no sun starting at some midnight

$\mathrm{TH}(\mathrm{Tahs}) := \mathrm{if}(\mathrm{Th} < \mathrm{Tahs}, \mathrm{Th}, \mathrm{Tahs})$

As the temperature of the attic heat store declines, it eventually hits Th, the desired temperature of the habitable space. The temperature of the habitable space then declines in step with the temperature of the attic heat store, remaining equal to it for the remainder of the decline of the temperature of the attic heat store.

$$\mathrm{PwrLossWalls}(\mathrm{Tahs}, t) := (\mathrm{TH}(\mathrm{Tahs}) - \mathrm{Ta}) \cdot \begin{bmatrix} (\mathrm{Gewn\_walls} + \mathrm{Gwin\_ewn}) \ldots \\ + ((\mathrm{clock}(t) \geq 9) \cdot (\mathrm{clock}(t) < 15) \cdot (\mathrm{Gs\_wall} + \mathrm{Gwin\_s}) \end{bmatrix}$$

South wall loses energy only between 9:00 AM and 3:00 PM

$\mathrm{PwrLossTCS}(\mathrm{Tahs}) := \mathrm{Gcs} \cdot (\mathrm{Tahs} - \mathrm{Ta})$

$\mathrm{PwrLossFloor}(\mathrm{Tahs}) := \mathrm{Gfloor} \cdot (\mathrm{TH}(\mathrm{Tahs}) - \mathrm{Tg})$

$\mathrm{PwrAirLoss}(\mathrm{Tahs}) := (\mathrm{TH}(\mathrm{Tahs}) - \mathrm{Ta}) \cdot \mathrm{NewAirLossPerDegree}$

$$\begin{aligned}\mathrm{PwrLoss}(\mathrm{Tahs}, t) := {} & \mathrm{PwrLossWalls}(\mathrm{Tahs}, t) \ldots \\ & + \mathrm{PwrLossTCS}(\mathrm{Tahs}) \ldots \\ & + \mathrm{PwrLossFloor}(\mathrm{Tahs}) \ldots \\ & + \mathrm{PwrAirLoss}(\mathrm{Tahs}) - \mathrm{nonSolarHeatGain}\end{aligned}$$

$\mathrm{hours} := 1 .. 3000$

$\mathrm{TCS}_0 := \mathrm{Tahs}$

Starting temperature for the attic heat store

$\mathrm{TCS}_0 = 100\,°\mathrm{F} \qquad \mathrm{TCS}_0 - 32\ \mathrm{F} = 37.8\,°\mathrm{C}$

Difference equation for the temperature of the attic heat store:

$$TCS_{hours} := TCS_{hours-1} - \frac{1}{thermalCapacity} \cdot PwrLoss\left(TCS_{hours-1}, hours-1\right) \cdot 1\ hr$$

$Thh_0 := Th$ Starting temperature for the habitable space

Thh_0 $Thh_0 = 38.9\,°C$

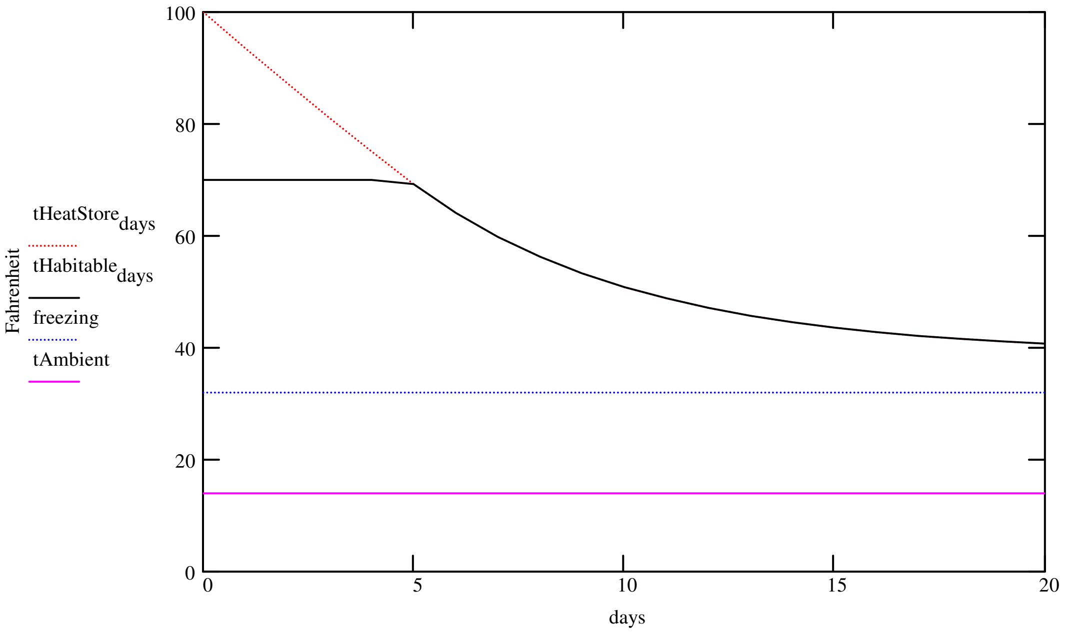
$$Thh_{hours} := TH\left(TCS_{hours}\right)$$

$tHeatStore := \frac{TCS}{F}$ $tHabitable := \frac{Thh}{F}$ $tAmbient := \frac{Ta}{F}$ $freezing := 32$

We have calculated with hour ticks for accuracy, but we graph with day ticks.

$days := 0 .. 125$

$tHeatStore_{days} := tHeatStore_{days \cdot 24}$ $tHabitable_{days} := tHabitable_{days \cdot 24}$



Temperature (F) decline with no sun

$tAmbient = 14$ $nonSolarHeatGain = 600\ W$

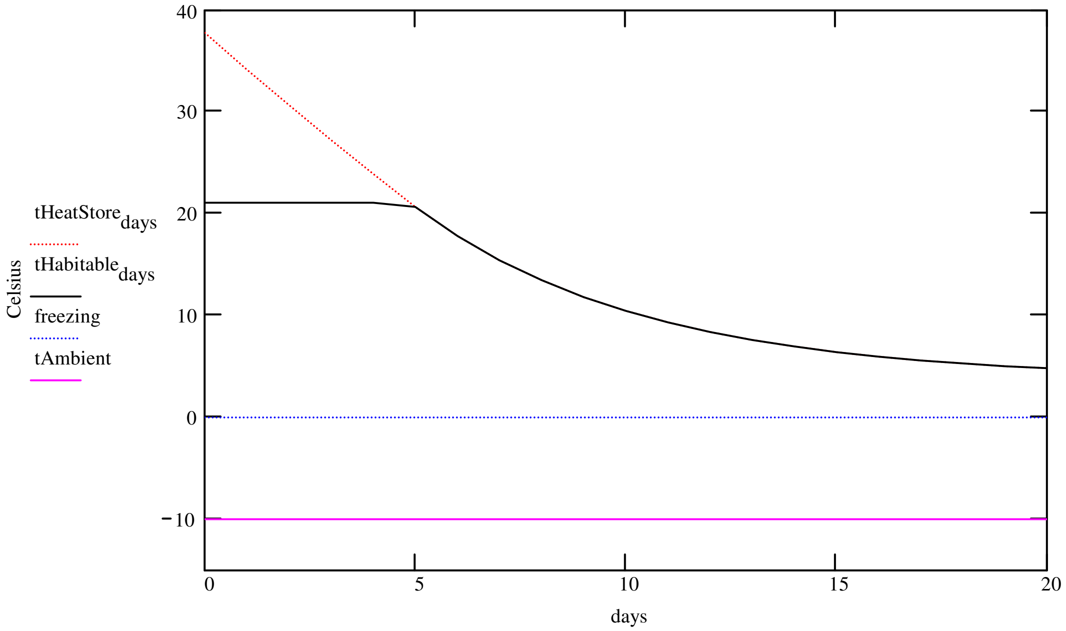
$$thermalCapacity = 2.2 \cdot 10^4 \,° \frac{Btu}{F}$$

$tHeatStore_0 = 100$ $tHabitable_0 = 70$ $tHabitable_7 = 59.8$ $tHabitable_{10} = 50.8$

$tHabitable_{31} = 39.1$

$\mathrm{tHeatStore} := \frac{\mathrm{TCS} - 32\ \mathrm{F}}{\mathrm{C}}$ $\quad$ $\mathrm{tAmbient} := \frac{\mathrm{Ta} - 32\ \mathrm{F}}{\mathrm{C}}$ $\quad$ $\mathrm{tHabitable} := \frac{\mathrm{Thh} - 32\ \mathrm{F}}{\mathrm{C}}$ $\quad$ $\mathrm{freezing} := 0$

$\mathrm{tHeatStore}_{\mathrm{days}} := \mathrm{tHeatStore}_{\mathrm{days}\cdot 24}$ $\quad$ $\mathrm{tHabitable}_{\mathrm{days}} := \mathrm{tHabitable}_{\mathrm{days}\cdot 24}$



Temperature decline (C) with no sun

$\mathrm{tAmbient} = -10$ $\quad$ $\mathrm{nonSolarHeatGain} = 600\ \mathrm{W}$

$\mathrm{tHeatStore}_{0} = 37.8$ $\quad$ $\mathrm{tHabitable}_{0} = 21.1$ $\quad$ $\mathrm{tHabitable}_{7} = 15.5$ $\quad$ $\mathrm{tHabitable}_{31} = 3.9$

Simulation of December with fixed solar aperature and grid on:

$\text{airHeaterGlazingArea} := 40\ \text{m}^2$

$\text{airHeaterGlazingArea} = 430.6\,\text{ft}^2$

$\text{solarPwrDensity}_0 := 0\ \dfrac{\text{W}}{\text{m}^2}$

Between midnight and 1 AM on december 1

$$\text{solarPwrDensity}_{\text{hours}} := \text{if}\left[(\text{clock}(\text{hours}) \geq 9)\cdot(\text{clock}(\text{hours}) < 15), \frac{1}{6\cdot\text{hr}}\cdot\text{irradiancePerDayOttawa}_2, 0\ \frac{\text{W}}{\text{m}^2}\right]$$

$$\text{solarPowerGain}_{\text{hours}} := \text{airHeaterGlazingArea}\cdot\text{airHeaterEfficiency}\cdot\text{solarPwrDensity}_{\text{hours}}$$

$\text{TAHS}_0 := \text{Tahs}$

$\text{TAHS}_0 = 100\,\text{F}$

$$\begin{aligned}\text{TAHS}_{\text{hours}} := {} & \text{TAHS}_{\text{hours}-1} \ldots \\ & + -\frac{1}{\text{thermalCapacity}}\cdot\text{PwrLoss}\left(\text{TAHS}_{\text{hours}-1}, \text{hours}-1\right)\cdot 1\ \text{hr} \ldots \\ & + \frac{1}{\text{thermalCapacity}}\cdot\text{solarPowerGain}_{\text{hours}-1}\cdot 1\ \text{hr}\end{aligned}$$

$\text{Thh}_0 := \text{Th}$

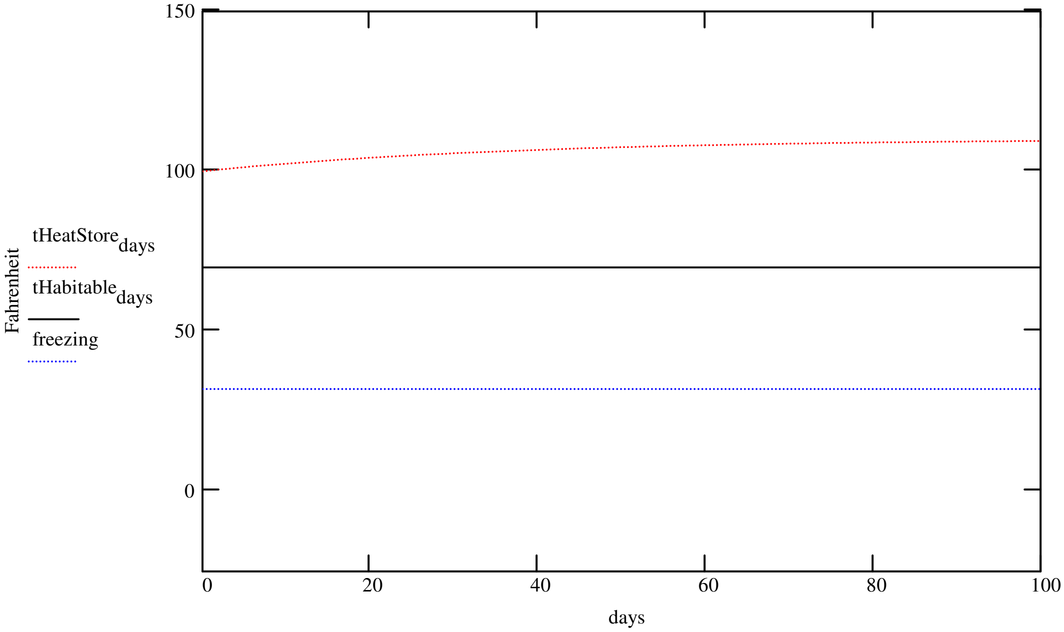
Starting temperature for the habitable space

$\text{Thh}_0 = 70\,\text{F}$ $\text{Thh}_0 = 38.9\,\text{C}$

$\text{Thh}_{\text{hours}} := \text{TH}\left(\text{TAHS}_{\text{hours}}\right)$

$\text{tHeatStore} := \dfrac{\text{TAHS}}{\text{F}}$ $\text{tHabitable} := \dfrac{\text{Thh}}{\text{F}}$ $\text{tAmbient} := \dfrac{\text{Ta}}{\text{F}}$ $\text{freezing} := 32$

$\text{tHeatStore}_{\text{days}} := \text{tHeatStore}_{\text{days}\cdot 24}$ $\text{tHabitable}_{\text{days}} := \text{tHabitable}_{\text{days}\cdot 24}$



December with typical (NASA) sun

nonSolarHeatGain = 600 W

$tHeatStore_0 = 100$ tAmbient = 14

$tHabitable_0 = 70$ $tHabitable_{10} = 70$ $tHabitable_{31} = 70$

$airHeaterGlazingArea = 40 \cdot m^2$

$tHeatStore_{124} = 109.8$