Making the Business Case for Increased Use of Thermal Insulation on Domestic Hot Water Distribution Systems

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National Institute of Building Sciences 2012 Recommendations

- Energy & Water Efficiency Topical Committee -

***“Moving Forward: In-Depth Findings and Recommendations from the Consultative Council”*.**

Determine the need for a potential study or extrapolation of existing data to determine the impact of thermal insulation on both energy and water use on portable hot water, and other similar distribution systems, and to examine the business case and return on investment of that opportunity.

National Institute of BUILDING SCIENCES

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"Determine the Energy and Water Savings Associated with Increased Use of Thermal Insulation"

Current Committee Members

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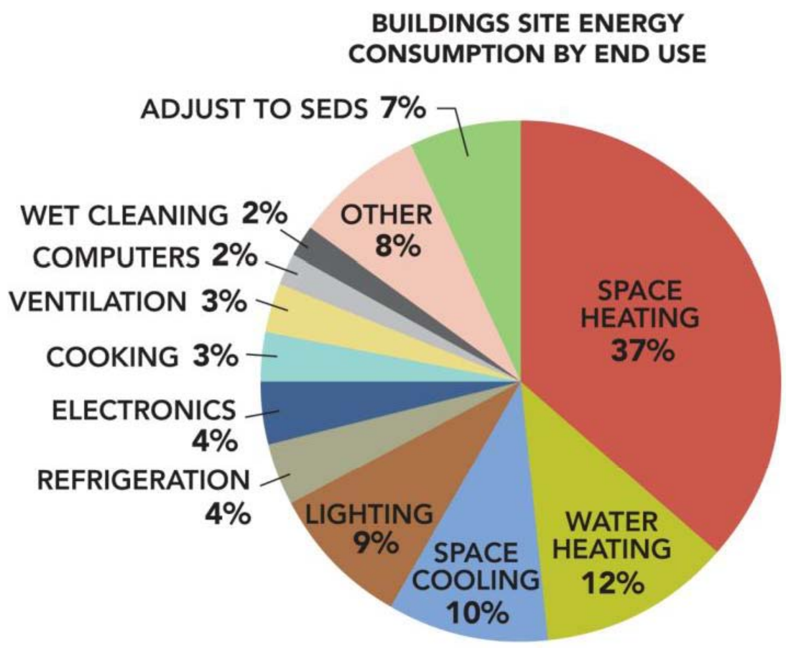
Affiliated International Management
Building Owners & Managers Association (BOMA)
Department of Energy
Eastern Research Group (ERG) – EPA Water Sense Program
International Facility Management Association (IFMA)
National Institute of Standards & Technology (NIST)
National Institute of Building Sciences (NIBS)
North American Insulation Manufacturers Association (NAIMA)
International Association of Plumbing and Mechanical Officials (IAPMO)
Lawrence Berkeley National Laboratory

Energy Consumed for Water Heating is Significant



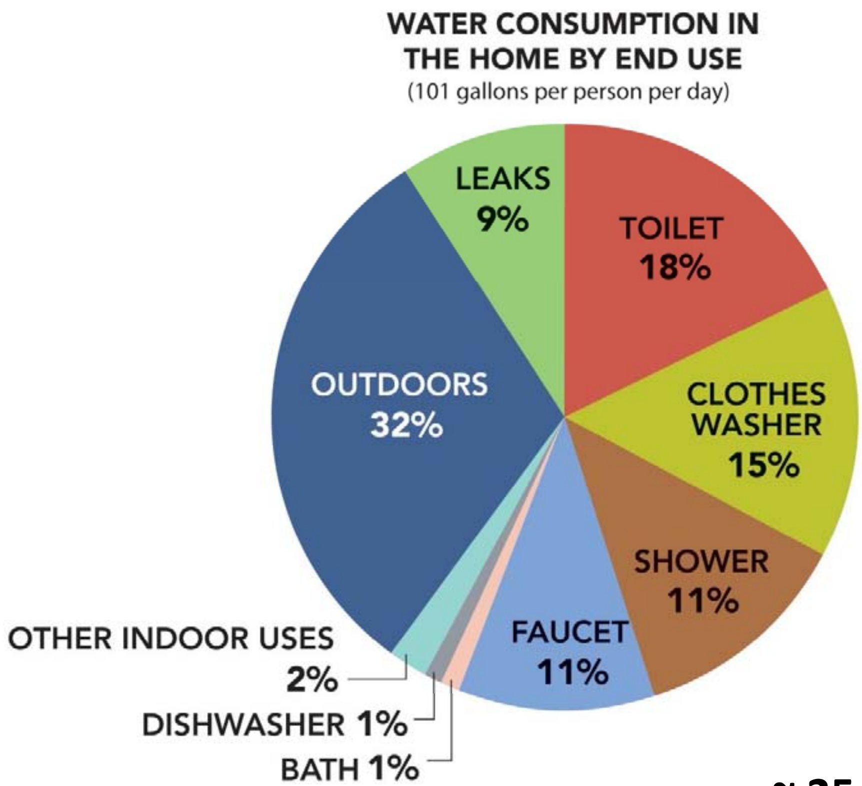
Site Energy for Water Heating

All Buildings	**12%**	**2.51 Quads**
Residential	**18%**	**1.92 Quads**
Commercial	**7%**	**0.58 Quads**

On a Primary Energy Basis, Water Heating in Buildings Requires 3.63 Quads/yr
(~4% of the Annual U.S. Energy Consumption)

Source: U.S. Department of Energy: 2011 Buildings Energy Data Book

Water Usage in Buildings is Also Significant



Water Usage Estimates

All uses	**410 bgd***
Residential	**29.4 bgd**
Commercial	**10.2 bgd**

* bgd = Billion gallons per day

~ 25 gpd/person is heated

Source: U.S. Department of Energy: 2011 Buildings Energy Data Book

Introduction

- **Thermal Insulation** is a Proven Technology for Reducing Heat Losses from Hot Water Piping Systems
- Common Sense Approach: You've paid to heat the water - keep it warm until it's needed!
- All Current Building Energy Codes and Standards Require Insulation (in varying degrees) on Domestic Hot Water Distribution Systems

What's the Business Case?

From the California Energy Commission

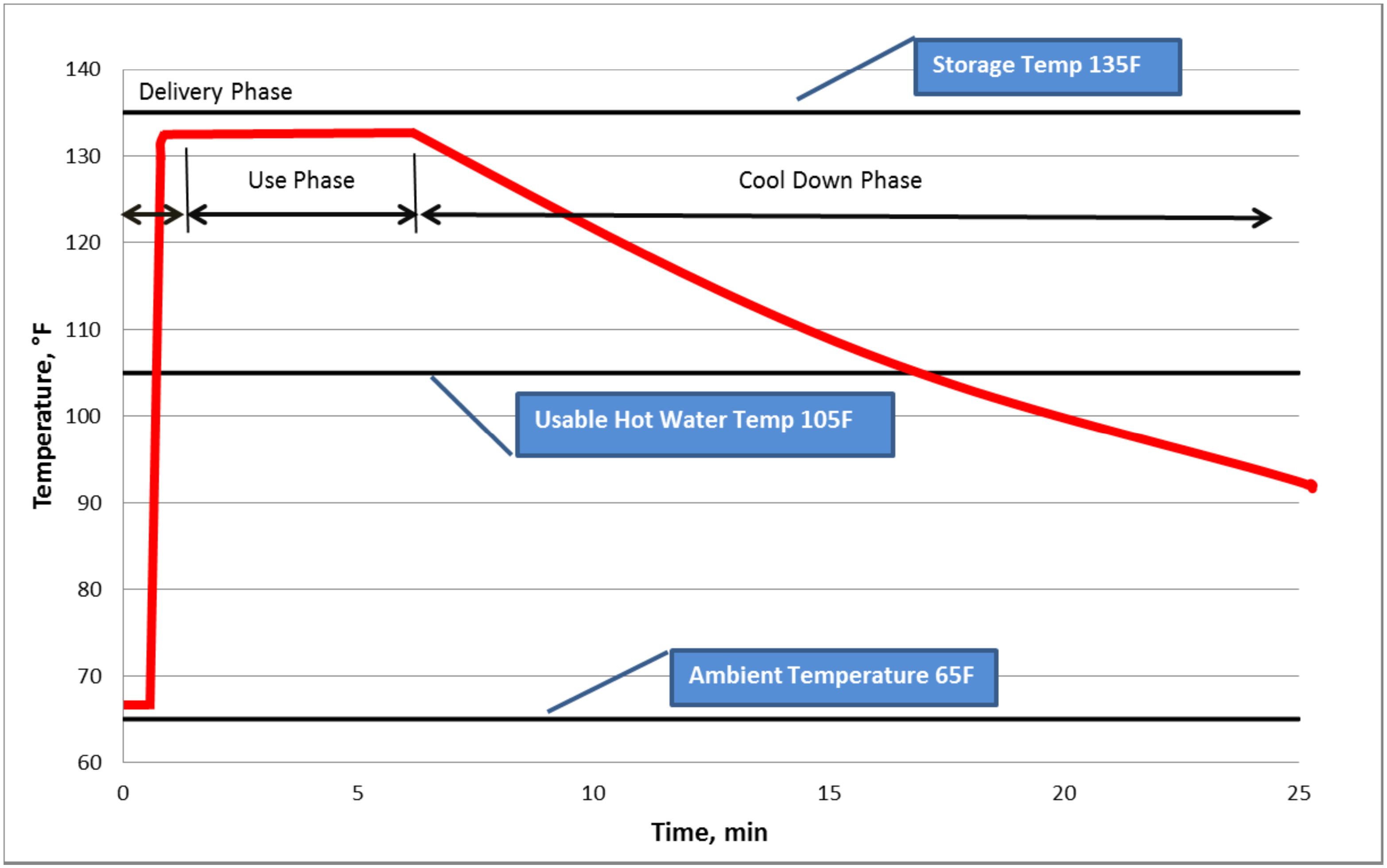
"Pipe insulation offers benefits in reducing heat loss, delivering hotter water to fixtures, and reducing hot water waste associated with cool downs between draws. All piping ¾" or larger should be insulated. . . .Insulating all piping certainly represents a Best Practice approach, but is likely not cost-effective for most ½" and smaller piping."

Ref: Residential Water Heating Program Final Report, Gas Technology Institute for CEC, CEC-500-2013-060 Dec 2012.

International Energy Conservation Code Recent Actions:

Will require insulation with a minimum thermal resistance of R-3 for hot water piping ¾" and larger in diameter. (section R403.5.3)

Insulating Hot Water Lines Can Save Energy, Water, and Time



Opportunities for Savings

- **During Delivery Phase**
  - Shorten the time waiting until water is hot enough to use?
- **During the Use Phase**
  - Minimize the temperature drop in DWH piping.
  - Ability to "dial back" the storage temperature?
- **During the Cool Down Phase**
  - Maximize the chances of avoiding "Cold Starts"

“Back-of-the-Envelope” Economics for a 1” Line

- **For a 1” copper, 25’ long branch line**
- **3 showers/day (122 hrs/yr)**
  - Energy Cost Saving during use phase = $3.75/yr
  - Energy Cost Saving **avoiding 2 cold starts/day** = $19.71
  - Water Cost Savings **avoiding 2 cold starts/day** = $12.41
  - Total Cost Savings = $35.87
  - Cost to Insulate 25’ = $153
  - **Simple Payback Period** **4.3 yr**

Conclusions from Back-of-the-Envelope Calculations

- For DHW Recirculating Loops and Heat Traced Piping
  - Insulation is a "No Brainer"
- For Other Lines
  - Insulation May be Justified, Depending On
    - Frequency, Duration and Pattern of Usage
    - Cost of Energy and Cost of Water

Considering:

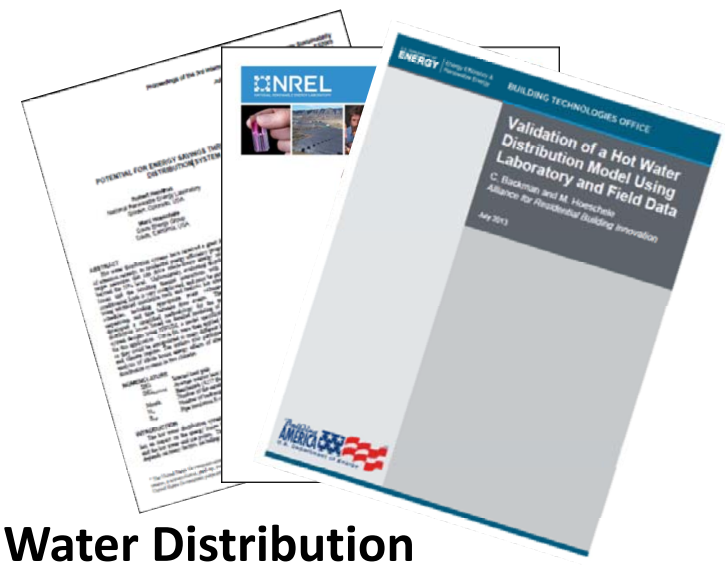
- The anticipated escalation of the Cost of Energy and Water
- The relatively minor incremental cost of insulation
- The long Service Life of DHW piping systems

Energy Codes should require insulation on <u>all</u> DHW piping

Can These Potential Savings be Quantified/Verified?

- **Much Good Work Has Already Been Done:**
  - California Energy Commission
    - Title 24 Energy Standard
  - DOE’s Lawrence Berkley Laboratory (LBL)
  - DOE’s National Renewable Energy Laboratory (NREL)
    - DHW Event Generator
- **But Much Remains To Be Done**

Three Recent Reports of Note:



- Robert Hendron, et al
  “Potential for Energy Savings Through Residential Hot Water Distribution System Improvements”
  National Renewable Energy Laboratory (2009)

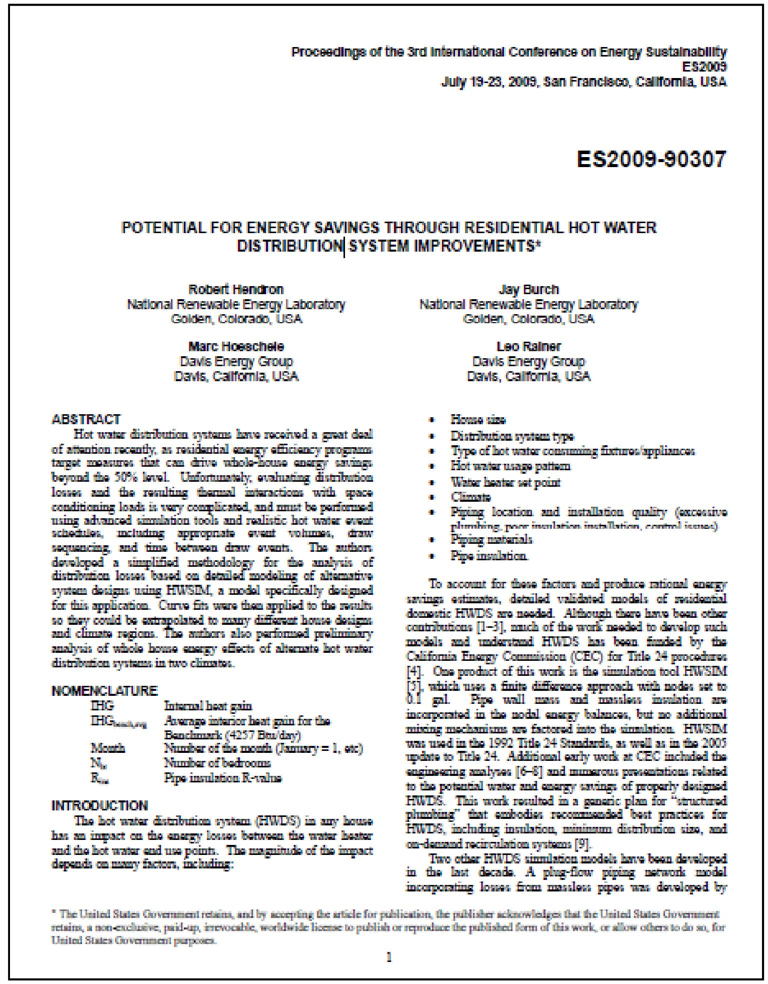
- Jeff Maguire, et al
  “An Analysis Model for Domestic Hot Water Distribution Systems”
  University of Colorado for NREL (2011)

- Christine Backman, and Marc Hoeschele
  “Validation of a Hot Water Distribution Model Using Laboratory and Field Data”
  Davis Energy Group for NREL (2013)

Summary of Hendron, et al

- Utilized HWSIM to model DHW Systems in a prototypical residence in St. Louis
- HWSIM uses weekly schedules of hot water draws
  - Time of day
  - Flow rate
  - Volume
  - Desired temperature (e.g. 105°F for showers)
  - Draw type (i.e. appliance or min temp)
- Included a Comparison of Insulated vs Non-Insulated Cases

Ref: Hendron, R., et al (2019). "Potential for Energy Savings through Residential Hot Water Distribution Systems Improvements" Proceedings of the ASME 3rd International Conference on Energy Sustainability, July 2009 ES2009-90307



Proceedings of the 3rd International Conference on Energy Sustainability
ES2009
July 19-23, 2009, San Francisco, California, USA

ES2009-90307

POTENTIAL FOR ENERGY SAVINGS THROUGH RESIDENTIAL HOT WATER DISTRIBUTION SYSTEM IMPROVEMENTS*

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ABSTRACT

Hot water distribution systems have received a great deal of attention recently, as residential energy efficiency programs target measures that can drive whole-house energy savings beyond the 50% level. Unfortunately, evaluating distribution losses and the resulting thermal interactions with space conditioning loads is very complicated, and must be performed using advanced simulation tools and realistic hot water event schedules, including appropriate event volumes, draw sequencing, and time between draw events. The authors developed a simplified methodology for the analysis of distribution losses based on detailed modeling of alternative system designs using HWSIM, a model specifically designed for this application. Curve fits were then applied to the results so they could be extrapolated to many different house designs and climate regions. The authors also performed preliminary analysis of whole house energy effects of alternate hot water distribution systems in two climates.

NOMENCLATURE

IHG	Internal heat gain
$IHG_{bench,avg}$	Average interior heat gain for the Benchmark (4257 Btu/day)
Month	Number of the month (January = 1, etc)
N_{br}	Number of bedrooms
R_{ins}	Pipe insulation R-value

INTRODUCTION

The hot water distribution system (HWDS) in any house has an impact on the energy losses between the water heater and the hot water end use points. The magnitude of the impact depends on many factors, including:

- House size
- Distribution system type
- Type of hot water consuming fixtures/appliances
- Hot water usage pattern
- Water heater set point
- Climate
- Piping location and installation quality (excessive plumbing, poor insulation installation, control issues)
- Piping materials
- Pipe insulation.

To account for these factors and produce rational energy savings estimates, detailed validated models of residential domestic HWDS are needed. Although there have been other contributions [1–3], much of the work needed to develop such models and understand HWDS has been funded by the California Energy Commission (CEC) for Title 24 procedures [4]. One product of this work is the simulation tool HWSIM [5], which uses a finite difference approach with nodes set to 0.1 gal. Pipe wall mass and massless insulation are incorporated in the nodal energy balances, but no additional mixing mechanisms are factored into the simulation. HWSIM was used in the 1992 Title 24 Standards, as well as in the 2005 update to Title 24. Additional early work at CEC included the engineering analyses [6–8] and numerous presentations related to the potential water and energy savings of properly designed HWDS. This work resulted in a generic plan for "structured plumbing" that embodies recommended best practices for HWDS, including insulation, minimum distribution size, and on-demand recirculation systems [9].

Two other HWDS simulation models have been developed in the last decade. A plug-flow piping network model incorporating losses from massless pipes was developed by

1

What is "HWSIM"

- A hot water distribution tool that models heat transfer and water use impacts
- Originally developed in 1990 by Davis Energy Group under contract to the California Energy Commission (CEC)
- Models a representative week of draws for each month, extrapolated to each month, and summed to calculate annual values

TABLE 2. USEFUL AND WASTED HOT WATER BREAKDOWN FOR BENCHMARK DISTRIBUTION SYSTEM IN A 3-BEDROOM, 2-BATHROOM HOUSE

Use Point	Draws/ Yr	Use (Gal/Yr)	Hot Water Waste (Gal/Yr)	% Waste
Sink 1	926	398	395	49.8%
Sink 2	965	344	392	53.3%
Sink 3	1043	522	227	30.3%
Sink 4 (Kitchen)	7235	4368	957	18.0%
Shower 1	548	5101	677	11.7%
Shower 2	222	1689	189	10.1%
Tub 1	65	1141	91	7.4%
Tub 2	39	652	34	4.9%
Clothes Washer	365	5287	0	0
Dishwasher	196	1810	0	0
Annual (Gal/Yr)	**11,602**	**21,310**	**2,962**	**12.2%**
Daily Average (Gal/Day)	**31.8**	**58.4**	**8.1**	**12.2%**

Source: Hendron et al (2009)

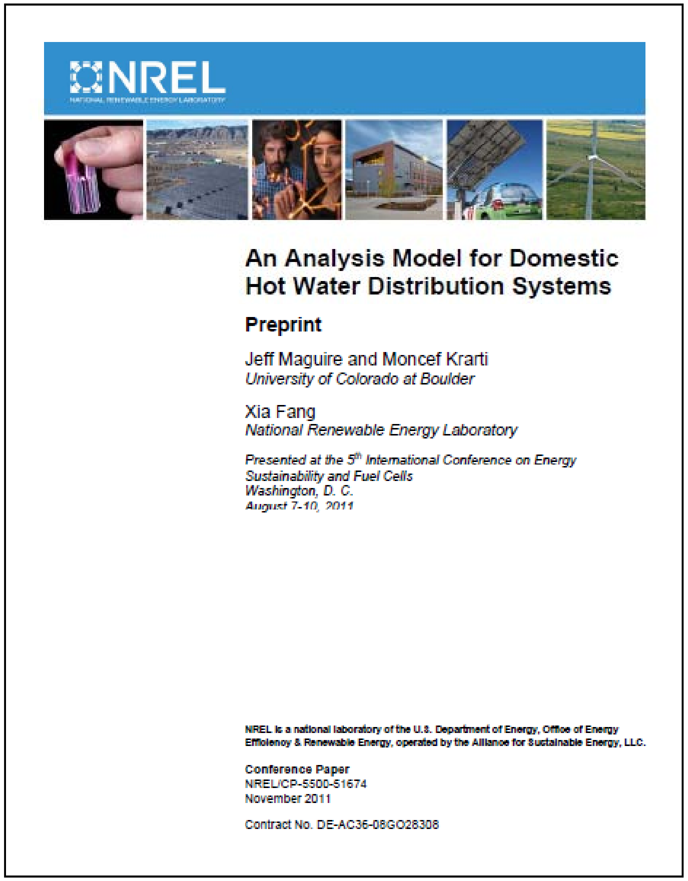
Hendron et al - Key Results

- **~3,000 gal/yr (12% of total hot water) is "wasted"** (waiting for water to be > 105°F)
- Insulation(R-2) saves energy in all cases, but the magnitude is small **(< $4/yr)**
- **But:**
  - **Savings (in energy and water) associated with "Wasted Water" not quantified or included**

(no reduction in hot water draws due to insulation)

Summary of Maguire, et al

- **Utilized TRNSYS to Simulate DHW Distribution Systems in a prototypical residence in 5 climates**
- **Validated model against laboratory data (Hiller data) and against the HWSIM model**
- **Utilized the "DHW Event Schedule Generator" (Hendron & Burch) to drive the model**
- **Included an evaluation of insulated (1/2" and 3/4" thick) vs uninsulated piping**


NREL
An Analysis Model for Domestic Hot Water Distribution Systems
Preprint
Jeff Maguire and Moncef Krarti
University of Colorado at Boulder
Xia Fang
National Renewable Energy Laboratory
Presented at the 5th International Conference on Energy Sustainability and Fuel Cells
Washington, D. C.
August 7-10, 2011
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Conference Paper
NREL/CP-5500-51674
November 2011
Contract No. DE-AC36-08GO28308

Ref: Maguire, J. et al; "An Analysis Model for Domestic Hot Water Distribution Systems" 5th International Conference on Energy Sustainability and Fuel Cells, August 2011, NREL/CP-5500-51674

What is TRNSYS?

- A **Tran**sient **Sy**stems **S**imulation program developed at the University of Wisconsin.
- Originally released in 1975
- Includes a library of standard components (e.g. pumps, solar collectors, tanks, pipes, and ducts)
- Utilizes an entire year of draw data **(6 sec draw profiles used)**

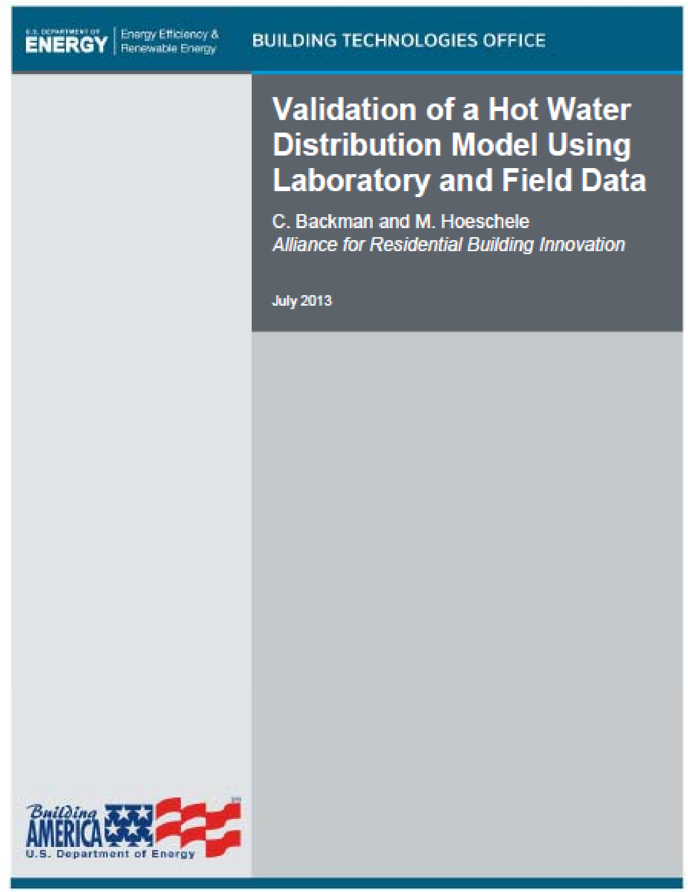
Maguire et al – Key Results

- Insulation reduces distribution losses by 20%
- This 20% reduction reduces the whole house energy consumption by ~ 7 therms/yr
  - **~ $8/yr at $1.20/therm for fuel**
  - Insulating just the portion in unconditioned space can save about 30% of this amount (or ~$2.50/yr)
- **But:**
  - **Savings (in energy and water) associated with "Wasted Water" not quantified or included**

(no reduction in hot water draws due to insulation)

Summary of Backman and Hoeschele

- **Utilized TRNSYS to Simulate DHW Distribution Systems in Typical Residences**
- **Validated Model against laboratory data (Hiller data) and field data (NREL Solar Row Project)**
- **Extended the model to a prototypical distribution system in 5 differing climates**
- **Used the DHW Event Schedule Generator to drive the model**
- **Included an evaluation of insulated (3/4" thick) vs uninsulated piping**


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES OFFICE

Validation of a Hot Water Distribution Model Using Laboratory and Field Data

C. Backman and M. Hoeschele
Alliance for Residential Building Innovation

July 2013

Building America
U.S. Department of Energy

Ref: Backman, C. ; Hoeschele, M. (2013). "Validation of a Hot Water Distribution Model Using Laboratory and Field Data." NREL Report No. SR-5500-58756; DOE/GO-102013-2945

Results of Model Validation Phase

- **Excellent Agreement Between Model Results and Laboratory Data:**
  - Outlet water temperatures agreed within 1.8°F
  - Time to achieve 105°F outlet typically agreed within 3.5%
  - Ratio of "wasted" hot water to pipe volume agreed within 8%
- **Excellent Agreement Against Field Data**
  - Monthly distribution losses agreed within 2%

Comparison for a Series of Kitchen Draws

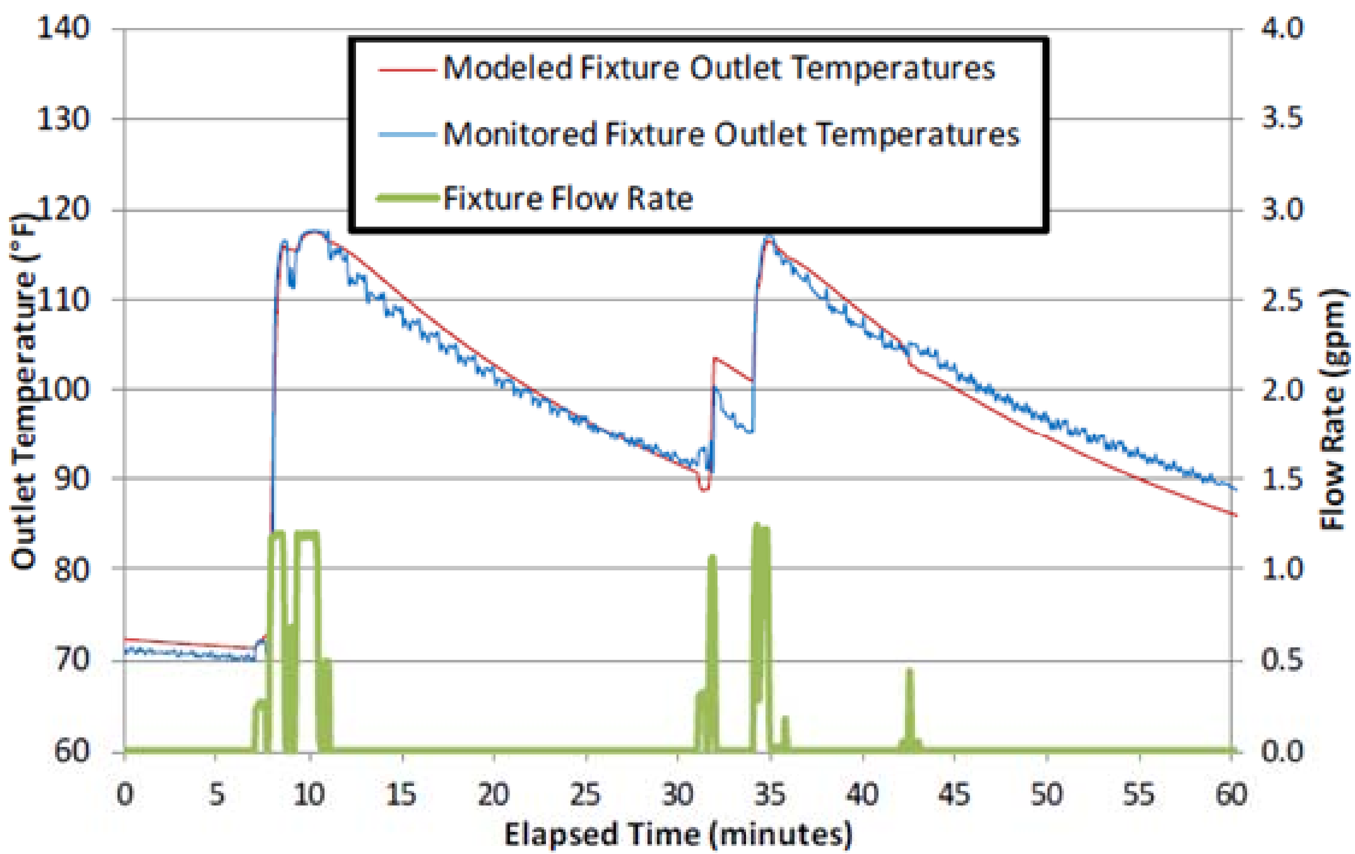


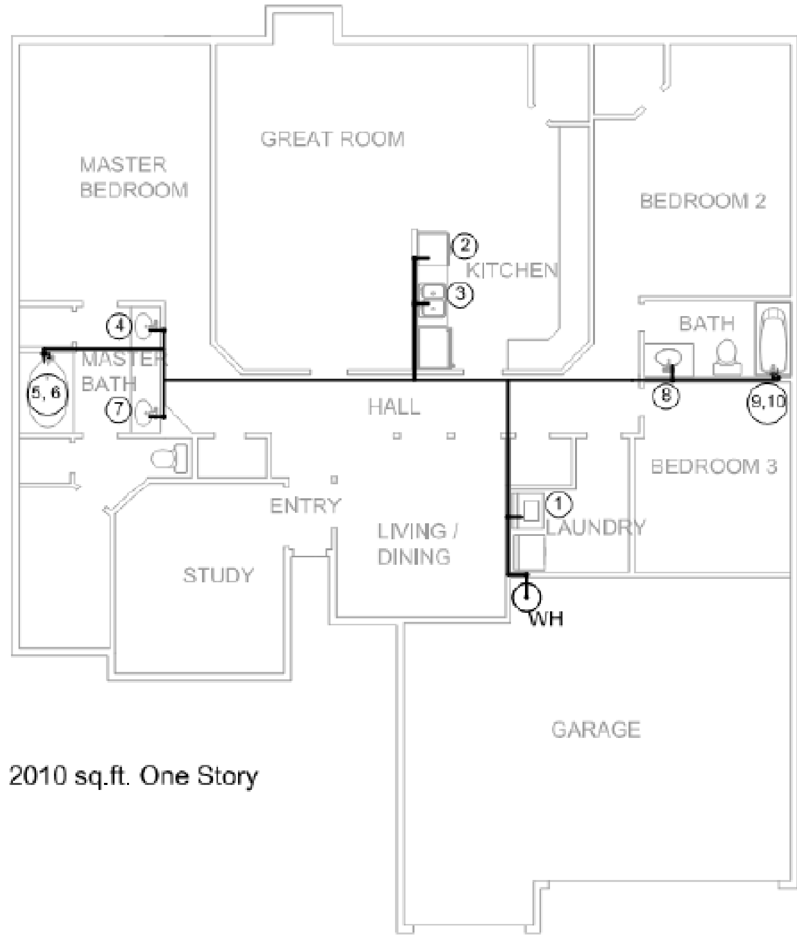
Figure 7. Comparison of simulated and actual pipe thermal decay with sequential draws

Extending the Model to Other Climates

- Modeled a Prototype House in Various Climates
- 3 bedroom, 2 bath home (2,010 ft^2)
- With and Without Pipe Insulation
- Five Climates (Denver, Chicago, Houston, Phoenix, and Seattle)
- Used **6 sec interval draw data** from the Domestic Hot Water Draw Generator (Hendron and Burch 2008)

Distribution System Layout

- **Trunk and Branch Layout**
- **10 fixtures**
- **Electric storage water heater in garage**
- **44 LF of ¾” copper tubing**
- **86 LF of ½” copper tubing**
- **Insulated cases assumed ¾” thick insulation**



2010 sq.ft. One Story

Selected Modeled Results

Modeled Results for Denver					
		Uninsulated	Insulated	Difference	% Diff
Water Heater Energy Input	kWh/yr	3,698	3,656	42	-1.1%
Water Heater Tank Losses	kWh/yr	377	377	0	0.0%
Water Heater Recovery Load	kWh/yr	3,322	3,279	42	-1.3%
Wasted Water Losses	kWh/yr	324	295	29	-8.9%
Pipe Heat Losses	kWh/yr	537	400	137	-25.5%
Useful Energy to Use Points	kWh/yr	2,461	2,584	-123	5.0%
Hot Water Use Rate	gpd	60.1	59.4	0.8	-1.3%
Wasted Rate	gpd	13.1	10.8	2.4	-17.9%

Source: Backman and Hoeschele (2013)

Backman and Hoeschele – Key Results

- Insulation reduces distribution losses by ~20%
- "Wasted Water" reduced by ~19%
- Water heater energy reduced by ~1% (~$5/yr)
- **But:**
  - **Savings (in energy and water) associated with "Wasted Water" not included**

(no reduction in hot water draws due to insulation)

Conclusions

- **Much has Already Been Done:**
  - Understanding DHW draws and development of the DHW Event Generator
  - Laboratory and Field Testing of DHW performance with and without insulation
  - **HWSIM** and **TRNSYS** have both been used to successfully model DHW system performance in multiple locations

Conclusions

- **Much Remains To Be Done:**
  - Understanding the interactions of DHW draws with occupant behavior and incorporation in DHW Distribution System Models

“Finally, a very important driver of event duration is the magnitude of hot water distribution losses. If the distribution system has long pipe runs, oversized pipe diameters, or large pipe losses upstream of a fixture, it is likely that the user will need to wait a significant length of time before hot water arrives at the fixture. In many cases this extends the duration of the hot water event, but not always. …..

Another complication is that the event schedules themselves have a large effect on the distribution losses, making the analysis an iterative process.

Hendron and Burch (2008)

Recommendations

- **Perform additional research on hot water usage patterns and interactions with occupant behavior**
- **Refine existing thermal models to incorporate occupant behavior models**
- **Evaluate alternative insulation strategies (e.g. comparisons to current code requirements)**
- **Extrapolate approach to commercial/institutional buildings (e.g. multifamily housing, hospitals, lodging, schools, etc.)**

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