



Use of Accurate Time-of-Use Measurements in Sub-metering

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Abstract

This white paper presents time-of-use and temperature measurement alternatives to metering an actual utility commodity, which can be attractive when metering is difficult or very expensive. For example, time-of-use measurement can be used when natural gas consumption must be determined inside a multifamily building living unit. Small volume gas meters present installation and accuracy challenges, have a high capital cost and are bulky, thus preventing them from being installed where space is at a premium. A second example is when hot water or chilled water is produced at a central location and then piped to individual living units. In these cases a widely practiced and generally accepted alternative is to accurately measure the on-time when gas is being consumed. The measured time-of-use, or temperature biased time is then used to determine the cost of energy used in each living unit. The cases presented below include fire place, hot water heater and furnace monitoring, and boiler heat or chilled water energy monitoring using either a measurement of time, temperature, or both.

Fire Place or Furnace Gas Monitoring

Many homes in multi-family communities have installed gas furnaces, hot water heaters or fireplaces served through a master gas meter on the property. This configuration is especially prevalent in the western United States, and in Vancouver BC. Gas fired fireplaces are used for warmth on chilly evenings and for ambience when friends and family gather together. It is not practical to retrofit a gas meter into each multi family unit due to the expense of the gas meter, poor measurement accuracy at low flow rates (pilot operation), limited space that will not accommodate a bulky traditional bellows meter and the gas piping configuration which may dictate a gas meter at each appliance. Compact ultrasonic gas meters are smaller, but even more expensive. Typically the entire property is served by one utility grade gas meter (often called the main or master meter) which measures the sum of all of the gas consumed by all of the multi family living units.

Wellspring Wireless has designed a special device for these applications - the Gas Appliance Monitor - which separately records the on-time for the pilot light and the on-time when the main gas burner is being operated. The pilot light on-time is determined by monitoring the thermocouple or thermopile circuit that is used by the gas valve to prove that the pilot flame is on. This feature is a basic safety requirement of all gas valves, so that each valve has this “prove flame is on” signal. If the flame goes out, then the valve immediately cuts off the flow of gas, thus preventing the room or appliance from being filled with gas. The Wellspring Wireless Gas Appliance Monitor measures the amount time that the pilot is on, in seconds. It also records the number of times the pilot light came on (in other words went from the off state to the on state). A similar method is used to measure the amount of time that the main fireplace or furnace burner is in operation. Each fire place and furnace gas valve has a local or remote switch (or thermostat) for turning on the gas to provide fuel to the main burner gas flame. The Wellspring Monitor is connected to this circuit and maintains a separate register for the on time of the main burner in the fireplace in seconds. It also logs the number of times the gas was turned on.

The Gas Appliance Monitor measures and reports the room temperature as well to support diagnostic algorithms, and can be ordered with one or two output relays which can be used to interrupt normal operation of the gas valve, limited by a minimum temperature. In this way, an apartment owner can remotely impose a limit the use of gas to a temperature they define, or curtail the use of an appliance (hot water heater or fireplace) in vacant units, or if the utility invoice is not paid.

Usage data is sent back to a host computer using a wireless mesh network that is compliant with IEEE 802.15.4. The time-of-use data measured by the monitoring device is written to non volatile memory (memory that remembers the data even if the power is removed from the monitoring device) in the monitoring device. The accuracy of the timing measurement meets the requirements of the NIST Handbook 44 which is referenced in the California Field Reference Manual 2009 Section 5.55, covering “Timing Devices” which states “tolerances on over registration and under registration shall be 3 seconds per hour but not to exceed one

minute per day”. This tolerance value is generally accepted nationwide for Time Clock and Time Recorders.

The Gas Appliance Monitor thus provide an accurate measurement of how many seconds the pilot light and the main burner gas flame are on. The next question is how this data can be used to translate the on-time measurements into utility consumption (in this case gas consumption) or utility cost. There are two methods that should be considered.

Method 1 – Time of use at the point of consumption to determine cost

The first method totals the time of operation of all gas appliances for the entire property, then determines the average BTU or dollar per hour consumed either by using the nameplate data (rating in BTU per hour) or by taking the main or master gas meter use (or the gas bill in dollars) less any common area loads and dividing the remainder by the sum of all hours from all Monitors over the same time period.

The steps involved in this process are listed below.

Method 1

- First, the time of operation of all units is totaled.
- If nameplate capacity data is used, simply multiply the time of use by the nameplate BTU per hour input rating, to determine the gas used.

It is now possible to present an invoice to the resident that shows their time of use (which is easy for them to relate to), their average capacity per unit of time (typically, BTU per hour), and their resulting energy used – then multiply that result by the applicable billing rate and their invoiced cost results.

It may be easier to simply determine the cost per minute, or cost per hour (dispensing with the gas BTU computation) and present an invoice that shows their time of use, the cost per unit of time, and their resulting bill. (This is the method required in California.) Naturally, the cost per unit of time may vary from month to month, because utility rates vary, and the BTU consumption rate may vary depending on whether residents operate their fireplace at high, medium or low fire. By billing for time at a cost per minute, the question of how much gas is used remains irrelevant – the invoice recovers the cost of providing the occupant with the pleasure of using their fireplace, or other appliance regardless of how much gas they may actually consume in the process.

Outlined below is an example, using Method 1 to determine main burner consumption based on the main gas meter data. This example represents data for one day but the same method could be used for one month or any other time period.

Method 1 – Time of use and BTU/H capacity to determine cost

First Example (Method 1)

Main gas meter consumption for one day	1,500,180 BTU
Pilot light BTU consumption in one day (nameplate data)	30
Price per Therm (100,000 BTU)	\$1.50

Unit #	device type	hours on	BTU/hour	Assigned BTU	Cost to occupant	Total cost
1	pilot	16 hours on	1.25	20	\$0.0003	
1	flame	16 hours on	17,647	282,353	\$4.2353	\$4.2356
2	pilot	24 hours on	1.25	30	\$0.0005	
2	flame	17 hours on	17,647	300,000	\$4.5000	\$4.5005
3	pilot	24 hours on	1.25	30	\$0.0005	
3	flame	8 hours on	17,647	141,176	\$2.1176	\$2.1181
4	pilot	0 hours on	1.25	0	\$0.0000	
4	flame	0 hours on	17,647	0	\$0.0000	\$0.0000
5	pilot	24 hours on	1.25	30	\$0.0005	
5	flame	20 hours on	17,647	352,941	\$5.2941	\$5.2946
6	pilot	8 hours on	1.25	10	\$0.0002	
6	flame	8 hours on	17,647	141,176	\$2.1176	\$2.1178
7	pilot	24 hours on	1.25	30	\$0.0005	
7	flame	0 hours on	17,647	0	\$0.0000	\$0.0005
8	pilot	24 hours on	1.25	30	\$0.0005	
8	flame	16 hours on	17,647	282,353	\$4.2353	\$4.2357
Total				1,500,180	\$22.5027	\$22.5027
Total hours pilot on		144 hours on		180	\$0.0027	
Total hours burner on		85 hours on		1,500,000	\$22.5000	
Capacity = 1,500,000/85 =		17,647 BTU /hour		1,500,180	\$22.5027	

Method 2 uses the BTU per hour rating of the pilot light and the BTU per hour rating of the fireplace (or another assigned consumption rate) in order to compute the BTU consumed (hours times capacity in BTU/hr = consumption). The process for Method 2 has six steps.

- First, the time of operation for each fireplace is multiplied by the nameplate capacity of each fireplace to determine the capacity adjusted time of operation
- Second, these values (capacity adjusted time of operation) are totaled for the property.
- Third, the measured gas use is determined for the applicable period (this may require the addition of meters in the mechanical rooms), less any common area loads in order to determine the total energy consumed.
- Fourth, the total energy consumed is divided by the total capacity adjusted time of operation in all units, to determine the amount of energy consumed per unit of capacity adjusted time.
- Fifth, the capacity adjusted time of operation of each individual fireplace or furnace monitor is multiplied by the energy per unit of capacity adjusted time calculated in step 4 to determine the energy consumed.

- Finally, the energy consumed in each living unit from step 5 is divided by the time of operation in each unit, to determine the capacity consumed per unit of time in each dwelling unit.

The second example below uses the nameplate or assigned capacity of each burner. Method 1 is used for the pilot lights, and Method 2 is used for the main burners. The data set for this example is identical to the first. This allows the reader to compare the two methods.

Method 2

Main gas meter consumption for one day 1,500,180 BTU
 Pilot light BTU consumption in one day (nameplate data) 30 BTU/Day
 Burner Capacity (nameplate data varies) 15 to 30 k BTU/Hr
 Price per Therm (100,000 BTU) \$1.50

Unit #	device type	hours on	Capacity BTU / hour	Capacity Adjusted Hrs	BTU per Capacity Adj. Hrs	Assigned BTU	Cost to occupant	Total cost
1	pilot	16 hours on	1.25	20	1.000	20	\$0.0003	
1	flame	16 hours on	20,000	320,000	0.8108	259,459	\$3.8919	\$3.8922
2	pilot	24 hours on	1.25	30	1.000	30	\$0.0005	
2	flame	17 hours on	30,000	510,000	0.8108	413,514	\$6.2027	\$6.2032
3	pilot	24 hours on	1.25	30	1.000	30	\$0.0005	
3	flame	8 hours on	25,000	200,000	0.8108	162,162	\$2.4324	\$2.4329
4	pilot	0 hours on	1.25	0	1.000	0	\$0.0000	
4	flame	0 hours on	20,000	0	0.8108	0	\$0.0000	\$0.0000
5	pilot	24 hours on	1.25	30	1.000	30	\$0.0005	
5	flame	20 hours on	15,000	300,000	0.8108	243,243	\$3.6486	\$3.6491
6	pilot	8 hours on	1.25	10	1.000	10	\$0.0002	
6	flame	8 hours on	25,000	200,000	0.8108	162,162	\$2.4324	\$2.4326
7	pilot	24 hours on	1.25	30	1.000	30	\$0.0005	
7	flame	0 hours on	15,000	0	0.8108	0	\$0.0000	\$0.0005
8	pilot	24 hours on	1.25	30	1.000	30	\$0.0005	
8	flame	16 hours on	20,000	320,000	0.8108	259,459	\$3.8919	\$3.8923
Total				1,850,180		1,500,180	\$22.5027	\$22.5027
Total hours pilot on		144 hours on		180		180	\$0.0027	
Total hours burner is on		85 hours on		1,850,000		1,500,000	\$22.5000	
Factor = 1,500,000/1,850,000 =		0.8108 BTU/cap.adj hr				1,500,180	\$22.5027	

In this second example, the calculation for cost attributable to the pilot light's gas consumption is identical the first. The difference is that each gas fireplace maximum BTU consumption (or input) rate is known. This information is generally available on the name plate of the gas fireplace and is given in units of BTU per hour. For each fire place in each apartment, the BTU rating is multiplied by the number of hours that the flame was on to obtain the capacity adjusted time of operation, the sum of which is greater than the actual gas used by the burners by a factor of .8108. Essentially, we have determined that the average firing rate of the burners was 81.08% of the nameplate rating. By applying this factor to all the burners (which assumes they are all operated at 81.08%), we can obtain their gas use. Since the cost per therm (100,000 BTU) is known, the cost per dwelling unit can easily be calculated by computing the cost for the pilot and adding it to the cost for the gas fire place flame.

Discussion of Method 1 and Method 2

Note: both the examples for Method 1 and Method 2 use the same data set so that results can be compared.

Method 1 is a simple and straight forward means of using a time measurement to compute the cost of gas consumption in each living unit. This method is ideal if the fire place or furnace in each unit consumes gas at the same rate as all of the gas appliances in all of the units. It may not be true that all gas fire places are the same, and it is certainly not true that all fireplace operation occurs at full fire rate. Accordingly, this approach may be less accurate, since it does not account for differences in the size of gas fire places each occupant has installed and how each occupant has set the flame fuel rate knob (low, medium or high). Remember Method 1 uses accurate time of use as a means of allocating BTUs for each unit. The measurement of flame on time cannot accurately determine the actual gas consumption for each fireplace if firing rates are adjustable by the resident.

Method 1 invites less controversy if used simply to bill for the pleasure of enjoying the fireplace, billed on a cost per hour basis, regardless of gas usage.

Method 2 allocates the cost with consideration for differences in capacity rather than just time. This method requires an accurate inventory of the BTU capacity for each fire place. However, just as in Method 1, this method does not account for differences that may occur in the flame fuel knob (low, medium or high). Method 2 uses accurate time of use measurement, and the relative capacity of each unit as a means of allocating BTUs for each unit. The measurement of time, even when biased by appliance capacity, cannot accurately determine differences in actual gas consumption for each fireplace if firing rates are adjustable by the resident.

Both Method 1 and Method 2 provide a fairer allocation of the cost of the gas consumed than RUBS (Ratio Utility Billing System), or inclusion of this cost in fees or rent, because methods that do not make measurements essentially divide the total cost of gas consumed by the number of units. The “RUBS”, “in-rent” or “in-fees” method assumes that operating time and capacity in all units is the same. Note in both Method 1 and Method 2, unit 4 consumed no gas and was not charged. If no measurements were made, unit 4 would have paid for one eighth of the total BTU consumption.

The chart below compares Method 1, Method 2 and the RUBS method for the example property.

Compare Method 1 and Method 2 to RUBS

				1,500,180				
Main gas meter consumption for one day								
Pilot light BTU consumption in one day					30			"in-Fee"
Price per Therm (100,000 BTU)					\$1.50			"In-rent"
				Method 1	Method 1	Method 2	Method 2	RUBS
Unit #	device type	Capacity BTU / hour	Assigned BTU	Cost to occupant	Assigned BTU	Cost to occupant		
1	pilot	16 hrs on 1.25	20	\$0.0003	20	\$0.0003		
1	flame	15,000	282,353	\$4.2353	259,459	\$3.8919	\$2.8128	
2	pilot	24 hrs on 1.25	30	\$0.0005	30	\$0.0005		
2	flame	20,000	300,000	\$4.5000	413,514	\$6.2027	\$2.8128	
3	pilot	24 hrs on 1.25	30	\$0.0005	30	\$0.0005		
3	flame	8 hrs on 25,000	141,176	\$2.1176	162,162	\$2.4324	\$2.8128	
4	pilot	0 hrs on 1.25	0	\$0.0000	0	\$0.0000		
4	flame	15,000	0	\$0.0000	0	\$0.0000	\$2.8128	
5	pilot	24 hrs on 1.25	30	\$0.0005	30	\$0.0005		
5	flame	10,000	352,941	\$5.2941	243,243	\$3.6486	\$2.8128	
6	pilot	8 hrs on 1.25	10	\$0.0002	10	\$0.0002		
6	flame	8 hrs on 25,000	141,176	\$2.1176	162,162	\$2.4324	\$2.8128	
7	pilot	24 hrs on 1.25	30	\$0.0005	30	\$0.0005		
7	flame	0 hrs on 15,000	0	\$0.0000	0	\$0.0000	\$2.8128	
8	pilot	24 hrs on 1.25	30	\$0.0005	30	\$0.0005		
8	flame	16 hrs on 20,000	282,353	\$4.2353	259,459	\$3.8919	\$2.8128	
Total				1,500,180	\$22.5027	1,500,180	\$22.5027	\$22.5027

Some Wellspring customers have used a minor revision to Method 2 whereby they arbitrarily fix gas capacities of each fireplace at a single low number for all units, with the unallocated gas being divided equally in fees or rent. This approach provides ample incentive for residents to conserve, while avoiding the controversy which may arise over differences in fireplace capacity or firing rates. The time that the main burner is on is then multiplied by this fixed number of BTUs per hour, using Method 1. This method will not allocate all of the gas consumed by the main master meter, but it does provide for a very conservative method of time-based allocation, which accomplishes the intended result to encourage conservation behavior.

Central Boiler or Chiller Energy Monitoring

Another application for using time measurement is the allocation of space heating or cooling from a central boiler or chiller to each dwelling unit in a multi-family unit building. In this case, one or more Wellspring Energy Monitors are mounted in each living unit. For convenience, Wellspring offers a Green Thermostat which has an Energy Monitor inside, making installation very simple. The Wellspring Energy Monitor measures the amount of time in seconds that the thermostat calls for heating or cooling. A gas fired central boiler produces hot water and pumps the heated water to each unit – and in the summer, a chiller system produces chilled water that runs through the same piping system. In the dwelling unit

there is a fan coil in which a fan blows air over the heat exchanger (the coil) which contains the circulating heated or chilled water. The resulting warmed or cooled air is distributed through duct work to the entire living unit and provides for comfortable space heating or cooling.

The Wellspring Energy Monitor maintains separate registers for heating and cooling which provide an accurate measurement of the number of seconds the thermostat called for heating and cooling. This data is sent back to a host computer every hour using a redundant wireless mesh network that is compliant with IEEE 802.15.4. The data measured by the monitoring device is written to non volatile memory (memory that remembers the data even if the power is removed from the monitoring device). The accuracy of the timing measurement meets the requirements of the NIST Handbook 44 which is referenced in the California Field Reference Manual 2009 Section 5.55, covering “Timing Devices” which states “tolerances on over registration and under registration shall be 3 seconds per hour but not to exceed one minute per day”. This tolerance value is generally accepted nationwide for Time Clock and Time Recorders.

The Energy Monitor (either as part of a thermostat or a stand alone device) thus provides an accurate measurement of how many seconds there was a call for heating or cooling. The question is now, how can this data be used to translate the time-of-use into a utility consumption (in this case BTU of gas or KWH of chiller energy consumption) – or used to simply recover the cost to operate the boiler or chiller. There are four methods that should be considered.

Method 3 – Time of use with an assigned rate to determine cost

Method 3 assumes that every fan coil has the same operating capacity. This is the simplest method and it relies upon an external process to assign a cost for the period of time that the fan coil was in operation. This method is most often used for chiller plants when the chiller plant is dedicated to produce chilled water year round. In addition the chilled water plant may produce chilled water for a number of facilities, office buildings, retail establishments and multi family living units. Once a cost per fan-coil-hour is determined, then the amount of time cooling is used by each living unit is multiplied by the cost per hour and the billed amount is thus determined for each living unit. This example represents data for one day but the same method could be used for one month or any other time period.

Method 3

Price of chilled water cooling per fan-coil-hour

Unit #	device type		\$0.28 Cost per unit hour	Cost to occupant
1	fan coil	14 hours on	\$0.28	\$3.92
2	fan coil	5 hours on	\$0.28	\$1.40
3	fan coil	10 hours on	\$0.28	\$2.80
4	fan coil	0 hours on	\$0.28	\$0.00
5	fan coil	16 hours on	\$0.28	\$4.48
6	fan coil	8 hours on	\$0.28	\$2.24
7	fan coil	7 hours on	\$0.28	\$1.96
8	fan coil	12 hours on	\$0.28	\$3.36
9	fan coil	5 hours on	\$0.28	\$1.40
10	fan coil	3 hours on	\$0.28	\$0.84
Total				<u>\$22.40</u>
Total hours thermostats called for heat		80 hours on		\$22.40

Method 4 – Time of use with a computed energy use to determine cost

Method 4 is similar to Method 3 in that it assumes that every fan coil has the same operating capacity. The difference is that the BTU/hour is computed using the following four steps.

- First, the time of operation of all units is totaled.
- Second, the measured gas use of the boiler or electrical use of the chiller, or the cost of these utilities is determined for the applicable period (this may require the addition of meters in the mechanical rooms).
- Third, the total energy used (or cost of energy used) is divided by the total time of operation in all units, to determine the average amount of energy consumed per unit of time (typically, BTU per hour for heat, or KWH per hour (or KW) for cooling), or the cost per unit of time.
- Finally, the time of operation of each individual Thermostat is multiplied by the capacity (or cost per hour) calculated in step 3 to determine the energy (or cost) consumed at the boiler or chiller to meet the heating or cooling needs of each living unit.

This method does not account for differences in unit capacity which may be defined on the nameplate, or the result of operating the fan coil at different user-selectable fan speeds. As such, it may be wiser to simply define a cost per unit-hour to operate the boiler or chiller, and bill at a dollar rate per unit of time for the pleasure of heating and cooling operating capacity delivered to the living unit as and when needed, billed on a cost per hour basis, regardless of gas or electric usage associated with such operation.

Outlined below is an example for Method 4 heat billing. This example represents data for one day but the same method could be used for one month or any other time period.

Method 4

Main master gas meter consumption for one day 1,500,000 BTU
 Price per Therm (100,000 BTU) \$1.50
 Total cost of gas consumed in one day \$22.50

Unit #	device type		Cost per unit hour	Cost to occupant
1	fan coil	14 hours on	\$0.28125	\$3.94
2	fan coil	5 hours on	\$0.28125	\$1.41
3	fan coil	10 hours on	\$0.28125	\$2.81
4	fan coil	0 hours on	\$0.28125	\$0.00
5	fan coil	16 hours on	\$0.28125	\$4.50
6	fan coil	8 hours on	\$0.28125	\$2.25
7	fan coil	7 hours on	\$0.28125	\$1.97
8	fan coil	12 hours on	\$0.28125	\$3.38
9	fan coil	5 hours on	\$0.28125	\$1.41
10	fan coil	3 hours on	\$0.28125	\$0.84
Total				\$22.50
Total hours thermostats called for heat		80 hours on		
Cost per unit-hour of operation = \$22.50/80 =			\$0.28125 per unit-hour	

In Method 4, the total hours that all units called for heat is computed; (in this example the total is 80 hours). Next, the total cost to heat the property is determined. The cost per unit-hour is determined by dividing the total cost for the month by the total of all hours that all units called for heat (the cost per unit hour of operation in this example is \$0.028125). Finally this value is multiplied by the time of heat operation for each unit.

Method 5 – Time of use, nameplate and computed central energy

Method 5 discussed below, accounts for differences in capacity of each fan coil unit. Essentially, two steps are added to the previous process, creating a new variable called “capacity adjusted time-of-use”, which is used to allocate central energy to each fan coil or heating unit.

- First, the time of each unit is multiplied by the nameplate capacity of each unit to determine the capacity adjusted time of operation
- Second, these values (capacity adjusted time of operation) are totaled for the property.
- Third, the measured gas use of the boiler or electrical use of the chiller is determined for the applicable period (this may require the addition of meters in the mechanical rooms) in order to determine the total energy consumed.
- Fourth, the total energy consumed is divided by the total capacity adjusted time of operation in all units, to determine the amount of energy consumed per unit of capacity adjusted time.
- Fifth, the capacity adjusted time of operation of each individual Energy Monitor is multiplied by the energy per unit of capacity adjusted time calculated in step 4 to determine the energy consumed at the boiler or chiller to meet the heating or cooling needs of each living unit.

- Finally, the energy consumed in each living unit from step 5 is divided by the time of operation in each unit, to determine the capacity consumed per unit of time

Now, the resident can be presented with their time of use multiplied by their average capacity, resulting in the energy they consumed. Then a billing rate (per therm, or per kwh) can be applied, and the billed amount to be invoiced is the result.

Method 5

Main master gas meter consumption for one day					1,500,000 BTU			
Price per Therm (100,000 BTU)					\$1.50			
Total cost of gas consumed in one day					\$22.50			
Unit #	device type	Capacity BTU/hour	Capacity adjusted time of operation	Allocated Utility Consumption in BTU	Ave. Capacity in BTU per hour	Cost to occupant		
1	fan coil	14 hours on 25,000	350,000	1.07 375,000	26,786	\$5.63		
2	fan coil	5 hours on 10,000	50,000	1.07 53,571	10,714	\$0.80		
3	fan coil	10 hours on 15,000	150,000	1.07 160,714	16,071	\$2.41		
4	fan coil	0 hours on 20,000	0	1.07 0	0	\$0.00		
5	fan coil	16 hours on 25,000	400,000	1.07 428,571	26,786	\$6.43		
6	fan coil	8 hours on 15,000	120,000	1.07 128,571	16,071	\$1.93		
7	fan coil	7 hours on 10,000	70,000	1.07 75,000	10,714	\$1.13		
8	fan coil	12 hours on 15,000	180,000	1.07 192,857	16,071	\$2.89		
9	fan coil	5 hours on 10,000	50,000	1.07 53,571	10,714	\$0.80		
10	fan coil	3 hours on 10,000	30,000	1.07 32,143	10,714	\$0.48		
Total		80	155,000	1,400,000	1,500,000	144,643	\$22.50	

Energy used (1,500,000) / capacity adjusted hours (1,400,000) = 1.07

In this method, as in any, the determination of the central heating or cooling energy to be assigned to each living unit must be carefully determined. Ideally, boilers and chillers dedicated to supplying hot or chilled water to each living unit should be sub-metered. If common areas are also served, reductions should be applied based on relative floor-space or outside exposure area.

This method does not account for differences in boiler or chiller temperatures which may result from transport losses, nor does it account for thermal transfers between living units through walls or floor/ceilings. Naturally, heating or cooling loads in some units may be greater as well due to their exposure (facing north versus south).

This method uses accurate time-of-use measurements as a means to allocate central system BTUs or KWHs for each unit. This measurement cannot account for differences in the temperature of the water or the actual flow rate to each living unit, which are assumed to be constant during the billing period.

This method provides a fairer allocation of the cost of the energy consumed, when compared to simply dividing the total BTUs consumed (1,500,000) by the number of units (10) times

the cost per Therm (\$1.50). Note that in this method, unit # 4 consumed no gas and was not charged for any gas consumed; as opposed to the simple ratio method which would have charged unit # 4 for one eighth of the total BTU consumption.

Method 6 – Time of use, nameplate, temperature and computed central energy

Method 6 improves the allocation accuracy by measuring the boiler or chiller water temperature delivered to each living unit, after all transport losses. This approach may be facilitated in boiler systems by using a Wellspring Energy Monitor with a single temperature input only, placed at the mid-point of a baseboard radiation run serving the dwelling unit, or one Monitor may be placed at each radiator. This approach is especially helpful when the thermostatic valve that controls the flow of heating water is mechanically driven and therefore, there is no electrical circuit to monitor for time of operation.

It is important to place the Energy Monitor sensor in **EXACTLY** the same relative location of each living unit. The Wellspring Energy Monitor is designed with this application in mind, and can be easily mounted so that the sensor drops through the baseboard cover at the appropriate location which is identical in each living unit.

Whenever the temperature sensed is above 90 degrees F, the Energy Monitor records the “degree-minutes” which are the product of time incrementing in seconds ($1/60^{\text{th}}$ of a minute), and degrees above 90F. So, if the sensor saw 102 degrees F for one hour, it would record 720 degree minutes (60 minutes x (102-90, or 12) degrees). The Energy Monitor also records the number of seconds whenever the temperature is above 90 degree F.

Of course, every living unit does not have the same capacity heater, which is defined by the finned tube length in each living unit, or the relative size of the radiators. The fin tube length must be measured, and a capacity factor determined for each living unit which reflects the relative length of heat exchanger in each living unit.

Method 6 determines the energy required to serve each living unit in six steps.

- First, the degree-minute time of each unit is multiplied by its relative capacity to determine the capacity adjusted degree-minutes of operation
- Second, these values (capacity adjusted degree-minutes of operation) are totaled for all of the living units using the same boiler heat.
- Third, the measured gas use of the boiler is determined for the applicable period (this may require the addition of meters in the mechanical rooms) or the total cost of operation is determined.
- Fourth, the total energy used at the boiler is divided by the total capacity adjusted degree-minutes recorded in all units, to determine the average amount of energy consumed per capacity adjusted degree-minute of demand on the boiler system.
- Fifth, the capacity adjusted degree-minutes of operation for each individual Energy Monitor is multiplied by the energy per capacity adjusted degree-minute

calculated in step 4 to determine the energy consumed at the boiler to meet the heating or cooling needs of each living unit.

- Finally, the energy consumed in each living unit from step 5 is divided by the time of operation in each unit, to determine the capacity consumed per unit of time in each living unit.

Now, the resident can be presented with their time of use multiplied by their average capacity, resulting in the energy they consumed. Then a billing rate (per therm, or per kwh) can be applied, and the billed amount to be invoiced is the result. An example of Method 6 is shown below.

Method 6

Main master gas meter consumption for one day	1,500,000 BTU
Price per Therm (100,000 BTU)	\$1.50
Total cost of gas consumed in one day	\$22.50
Degree minute low temperature (degrees F) threshold	90

Unit #	device type	hours on	Degree minutes	Average Boiler Water Temp Sensed	fin tube length	Capacity adjusted degree minutes	Energy consumed per capacity adjusted degree minute	BTU allocation to each apartment unit	Average capacity in BTU per hour	Cost to occupant
1	fan coil	14 hours on	37,800	135	12	453,600	0.69	311,830	22,274	\$4.68
2	fan coil	5 hours on	12,600	132	8	100,800	0.69	69,295	13,859	\$1.04
3	fan coil	10 hours on	24,000	130	10	240,000	0.69	164,989	16,499	\$2.47
4	fan coil	0 hours on	0	N/A	12	0	0.69	0	N/A	\$0.00
5	fan coil	16 hours on	36,480	128	12	437,760	0.69	300,940	18,809	\$4.51
6	fan coil	8 hours on	21,600	135	14	302,400	0.69	207,886	25,986	\$3.12
7	fan coil	7 hours on	18,480	134	10	184,800	0.69	127,042	18,149	\$1.91
8	fan coil	12 hours on	28,800	130	10	288,000	0.69	197,987	16,499	\$2.97
9	fan coil	5 hours on	12,600	132	8	100,800	0.69	69,295	13,859	\$1.04
10	fan coil	3 hours on	7,380	131	10	73,800	0.69	50,734	16,911	\$0.76
Total		80	199,740			2,181,960	0.69	1,500,000	18,750	\$22.50

Energy consumed (1,500,000) / cap. adjusted degree minutes (2,181,960) = 0.69

Method 6 created registers for both time of operation and degree-minutes reflecting the temperature delivered by the system. Another measurement approach is possible, in which tracking of a thermostat call for heat (measuring time) is coupled with a temperature sensor mounted on the heating pipe. This approach is especially attractive when heating valves are all located in the boiler room, because one energy monitor can be used to establish time and degree-minute registers for up to 4 living units. (The Energy Monitor accepts up to 4 binary and 4 analog inputs).

The resulting registers are identical to those described above, and the method of determining the energy required to satisfy demand is the same – with the only advantage being that four living units can be monitored with one Energy Monitor.

The only disadvantage this approach introduces is that the temperature measured is at the boiler room, before transport losses, so the allocation to living units which suffer greater transport losses may be higher than those with lower transport losses. This simply adds one more inequity to others which are unavoidable in all buildings, regardless of the metering

system used, including living unit placement relative to weather affects, and thermal sharing which is unavoidable in all multi-family buildings. Differences in transport losses are arguably overwhelmed by these other inequities which cannot be avoided in multi-family buildings.

Measured Comfort – Ideal when thermal sharing dominates

The methods described above are all comprehended in ASHRAE Guideline 8. (ASHRAE stands for the American Society of Heating, Refrigeration, Air-Conditioning Engineers, and their Guideline 8 describes methods of measurement recommended in support of utility cost recovery programs for central heating and cooling systems). There is another method recommended in Guideline 8 for buildings that suffer gross inequities from thermal sharing and weather exposures.

In this method, energy is divided proportionally based on the difference between indoor and outdoor temperatures, integrated over time. So, if it is 38 degrees outside, and a resident maintains the living unit at 78 F, the resident will pay more than their neighbor who maintains their living unit at 68 F. In the former case, the difference between indoor to outdoor temperatures is 40 degrees, while the latter case is only 30 degrees – so the frugal neighbor should pay 75% of their wasteful neighbor.

This approach ignores the heat delivery system, and that losses might be greater in some units than others. This is appropriate in some buildings when much of the heating energy is delivered through thermal sharing, and load differences due to exposure are great.

Method 7 - Time of use, indoor and outdoor temperature

Wellspring implements this method by downloading the outdoor temperature to each Green Thermostat every few minutes. The Energy Monitor inside the Green Thermostat measures the room temperature every minute, and increments a register called “delta-degree minutes”, defined as the temperature difference from indoor to outdoor multiplied by time.

The distribution of boiler or chiller energy follows the same steps detailed previously, but in this case, the “capacity adjustment factor” should be based on the relative size of the living unit.

- First, the delta-degree-minute time of each unit is multiplied by its relative size of each living unit to determine the size adjusted delta-degree-minutes of operation.
- Second, these values (size adjusted delta-degree-minutes of operation) are totaled for the property.

- Third, the measured gas use of the boiler (or KWH used by the chiller) is determined for the applicable period (this may require the addition of meters in the mechanical rooms) or the total cost of operation is determined.
- Fourth, the total energy used by the central system is divided by the total size adjusted delta-degree-minutes recorded in all units, to determine the average amount of energy consumed per size adjusted delta-degree-minute of demand on the central system.
- Fifth, the size adjusted delta-degree-minutes of operation for each individual Energy Monitor is multiplied by the energy per size adjusted delta-degree-minute calculated in step 4 to determine the energy consumed at the boiler to meet the comfort conditions experienced in each living unit.
- Finally, the energy consumed in each unit should be divided by number of degree days reported to determine the average energy (therms or KWH) or energy cost per degree-day that is being charged.

Since the time of operation for the heating or cooling system in each apartment is not relevant in this method, it is not used. The Energy Monitor records time of use, but use of this register is limited to diagnostics which will reveal if residents are running the heat with the windows open, which should be associated with a penalty charge for each day this condition is detected.

Resident billing should simply show the average indoor temperature, the average difference in temperature, the resulting number of degree-days measured, the energy (or cost) per degree day, with the resulting energy required at the boiler or chiller to maintain their comfort level shown. Then multiply the result (therms or KWH) by the billing rate and the resident's invoiced cost results.

Method 7

Main master gas meter consumption for one day	1,500,000 BTU
Price per Therm (100,000 BTU)	\$1.50
Total cost of gas consumed in one day	\$22.50
average outside temperature	34 deg F

Unit #	device type	degree hours (indoor - outdoor) x time	Average indoor temp	Apart. Size in sq ft.	Size adjusted degree-hours	BTU per size adjusted degree hour	Allocated Utility Consumption in BTU	Capacity in BTU per degree-hour	Cost to occupant
1	radiators	912	72	850	775,200	0.1829	141,758	155	\$2.13
2	radiators	984	75	750	738,000	0.1829	134,955	137	\$2.02
3	radiators	1056	78	650	686,400	0.1829	125,519	119	\$1.88
4	radiators	816	68	1,000	816,000	0.1829	149,219	183	\$2.24
5	radiators	744	65	1,100	818,400	0.1829	149,658	201	\$2.24
6	radiators	960	74	875	840,000	0.1829	153,608	160	\$2.30
7	radiators	936	73	900	842,400	0.1829	154,046	165	\$2.31
8	radiators	912	72	1,010	921,120	0.1829	168,442	185	\$2.53
9	radiators	1008	76	625	630,000	0.1829	115,206	114	\$1.73
10	radiators	1032	77	1,100	1,135,200	0.1829	207,590	201	\$3.11
Total		9360		8,860	8,202,720	0.1829	1,500,000		\$22.50

Factor: BTU consumption / size adjusted degree-hours = 0.182866

Note that Unit number 4 never ran its heater in any of these examples, yet they maintained 68 degrees as their average temperature. Essentially, unit number 4 has been drawing energy from its neighbors, the hallway or the boiler room. If using methods 3, 4, 5 or 6, it is advisable to apply a minimum charge, so that no apartment can get by paying nothing, when they are clearly consuming heat that originated in the boiler room.

It is also noteworthy, that unit number 5 ran his heater for 16 hours this day, more than any of the other units, yet maintained a temperature of only 65 degrees. Clearly, this apartment is suffering excessive heat loss to neighbors and the ambient – and should probably be adjusted down to a minimum charge if methods 3, 4, 5 or 6 are used.

In our experience, if a minimum of 50% of the average is applied, along with a 150% maximum charge, about 25% of the apartments will be subject to these limits. As an owner, this is a pragmatic result, since no resident should skate by without paying, and no resident should be charged so much that they move out.

If such thermal sharing is extremely prevalent, such that more than 25% of units are affected by a minimum and maximum charge, method 7 should be considered. Method 7 also seems appropriate for apartments with multiple thermostatically controlled radiators, where the capital cost of one temperature monitor is far less than using 4 or 5 radiator monitors in each unit.

The table below compares results for methods 3, 4, 5, 6 and 7 in our example.

Compare Method 3, 4, 5, 6 & 7

Main master gas meter consumption for one day	1,500,000 BTU
Price per Therm (100,000 BTU)	\$1.50
Total cost of gas consumed in one day	\$22.50

Unit #		Method 3 Cost to occupant	Method 4 Cost to occupant	Method 5 Cost to occupant	Method 6 Cost to occupant	Method 7 Cost to occupant	RUBS*
1	14 hours on	\$3.92	\$3.94	\$5.63	\$4.33	\$2.13	\$2.25
2	5 hours on	\$1.40	\$1.41	\$0.80	\$1.03	\$2.02	\$2.25
3	10 hours on	\$2.80	\$2.81	\$2.41	\$2.58	\$1.88	\$2.25
4	0 hours on	\$0.00	\$0.00	\$0.00	\$0.00	\$2.24	\$2.25
5	16 hours on	\$4.48	\$4.50	\$6.43	\$4.95	\$2.24	\$2.25
6	8 hours on	\$2.24	\$2.25	\$1.93	\$2.89	\$2.30	\$2.25
7	7 hours on	\$1.96	\$1.97	\$1.13	\$1.81	\$2.31	\$2.25
8	12 hours on	\$3.36	\$3.38	\$2.89	\$3.10	\$2.53	\$2.25
9	5 hours on	\$1.40	\$1.41	\$0.80	\$1.03	\$1.73	\$2.25
10	3 hours on	\$0.84	\$0.84	\$0.48	\$0.77	\$3.11	\$2.25
Total	80	\$22.40	\$22.50	\$22.50	\$22.50	\$22.50	\$22.50

Conclusion

It is widely accepted in commercial buildings, that boiler and chiller systems consume far less energy than their incremental heating and cooling unit counterparts. But since the Arab oil embargo of 1973, and the Federal Energy Act of 1975, most multi-family buildings have been constructed with less efficient apartment sized systems, principally selected so that heating and cooling energy for each residence could be purchased by the resident directly from the gas or electric utility.

Sub-metering of wet thermal energy was not practical or cost effective in the past, so more efficient chiller and boiler system were no longer considered.

Today, precise measurement of wet BTU's remains impractical, principally because water meters cannot stand up to the rigor of operation between 3,000 and 4,000 hours per year. We have seen jobs where water flow measurement in re-circulating systems was attempted – meters lasted only 18 months.

In consequence, owners of older buildings with boiler and chillers had no alternative other than to include the cost of heating and cooling energy in-rent, or to simply allocate these energy costs based on a formula that does not account for differences in the behavior of residents. The result is that many residents operate both heating and cooling with their windows open – because they like the fresh air. Others heat to 80 degrees, because they like it warm. Waste is rampant. While this waste was not material to an owner's profitability prior to 1973, when gasoline sold for less than 30 cents per gallon, today it can turn a property upside down.

It wasn't until 1994 that ASHRAE (the Society of HVAC Engineers) published "Guideline 8". (See Wellspring's web site reference library). This nationally accepted standard describes 16 methods of allocating boiler and chiller expense based on measurements that recognize differences in set-points and resident behavior. The advantages and challenges of each method is discussed in engineering terms – as are the cost implications.

Since 1994, commercial measurement systems have been developed to deliver the measurement methods described in the ASHRAE Standard. These products and systems have been helped a great deal by the simultaneous emergence of radio-based data communication networks, which most recognize as Wi-Fi, or Bluetooth – the latest of which is ZigBee, specifically targeted at building control and monitoring applications.

And suppliers like Wellspring have gained a great deal of field experience – we know how to deal with thermal sharing issues, and we diagnose bad behavior from our data, including open windows and tampering. Systems have evolved and improved as our experience has grown.

Today, it is cost effective to retrofit measurement systems that comply with ASHRAE Guideline 8 to recover central system boiler and chiller energy. Today, we are actually seeing a resurgence

of chillers and boilers in new multi-family building designs, in an attempt to keep utility costs low, and exploit the growing demand for “Green” buildings. After all, central boiler and chiller systems ARE more efficient, if residents keep their consumption in check because they must pay for the energy they consume.

Today, it is no longer necessary that owners of buildings with boilers and chillers place their incomes at risk over the relative certainty of volatile energy prices. Wellspring offers 7 specific solutions – some of which are offered by others who employ one way radio or wired systems. The market for energy monitoring as we have described it is robust, and maturing with many active competitors.

The bottom line is this – the worlds most efficient systems can now be sub-metered, so residents pay only for what they consume. This provides a compelling incentive to conserve, which lowers heating and cooling costs in buildings with central systems relative to the competitors who use less efficient apartment sized HVAC units.

Wellspring’s average drop in consumption with sub-metering is 26%.

Simple payback on these systems is generally under 3 years.