FREE COOLING – OUTSIDE AIR ECONOMIZER

WHITE PAPER #11

It's like opening a window when it's hot inside and cool outside.

How much does it save? The easy answer is 'it depends.' To really find out, read further. You'll see there are a lot of factors.

Like all heat recovery concepts, a pre-requisite for success is to have the free heat (or free cooling) available at the same location and time as there is a need for it. The free heat in Atlanta has no practical use in Alaska because they are too far apart. Likewise, free cooling from outdoors doesn't provide any value unless it is warm indoors at that time.

Balance Temperature

Buildings are like boxes. They have thermal losses and gains through the shell (envelope), and they also have appliances and activities inside that generate heat. See **Figure 1.** There will be a point where the envelope loss just matches the internal heat gains and neither heating nor cooling is required; above this 'balance temperature', cooling will be required.

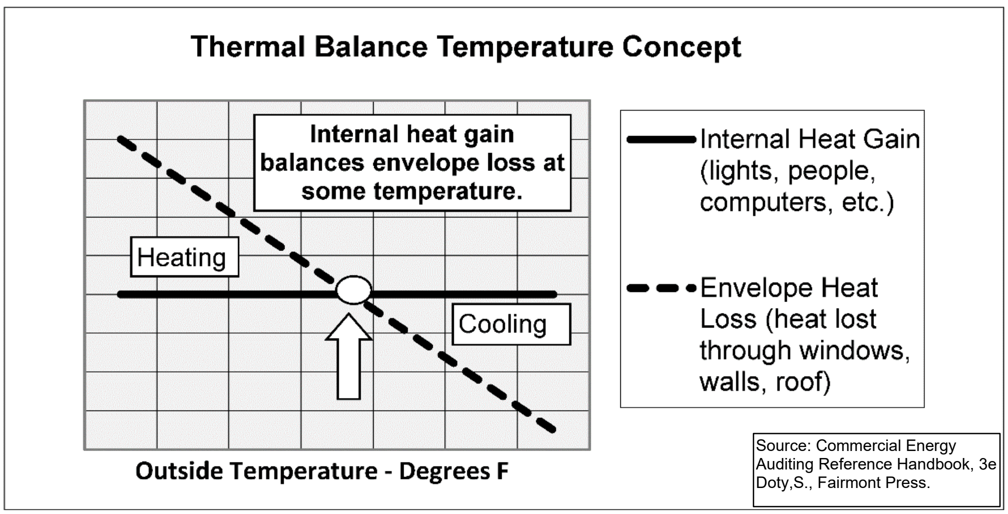

Figure 1. Thermal Balance Temperature

What is your building's balance temperature?

A building's thermal balance temperature can be estimated with a method called regression, but there are also clues. See **Table 1**. If there is a lot of heat-producing equipment inside, the building becomes self-heating and will include hours in cooling mode when it is cold outside. Opportunity! If the heating and cooling load is mostly from envelope (not a lot of equipment), the balance point will be higher which means it probably won't be hot inside while it is cold outside.

Economizer savings is dependent upon the building balance temperature

The thermal balance temperature is unique for each building. The magnitude of the envelope in relation to the internal gains creates a cooling load 'signature' for the building. This signature is an important factor in determining how much benefit can be expected from an air-side economizer. For example, the heating and cooling load for a house comes mostly from the envelope. So, when it's cold outside it's usually cold inside a house and this is why our homes are not good candidates for an air side economizer. Besides, we can just open a window.

In many commercial buildings, the heat produced by what goes on inside will offset heat losses in cool or cold weather, resulting in a need for some cooling even while cold outside. When this is the case an air-economizer is a benefit.

The greater the internal loads are, in proportion to the envelope losses, the greater the benefit of an air-economizer, because the thermal balance point is lower. With a low balance temperature, there are more hours when the building needs cooling *and it happens to also be cool outside*.

To sum it up: ***the lower the balance point, and the greater the number of hours this occurs, the greater the benefit.*** This is a big 'it depends' factor when asked how much an air economizer will save. In **Figure 2**, the shaded area shows the region of savings and it can be seen that this area will be larger (more savings) when the building balance temperature. As you look at the charts of hours, you will note there is a big difference in savings depending on balance temperature and also the number of hours per year the building is operated.

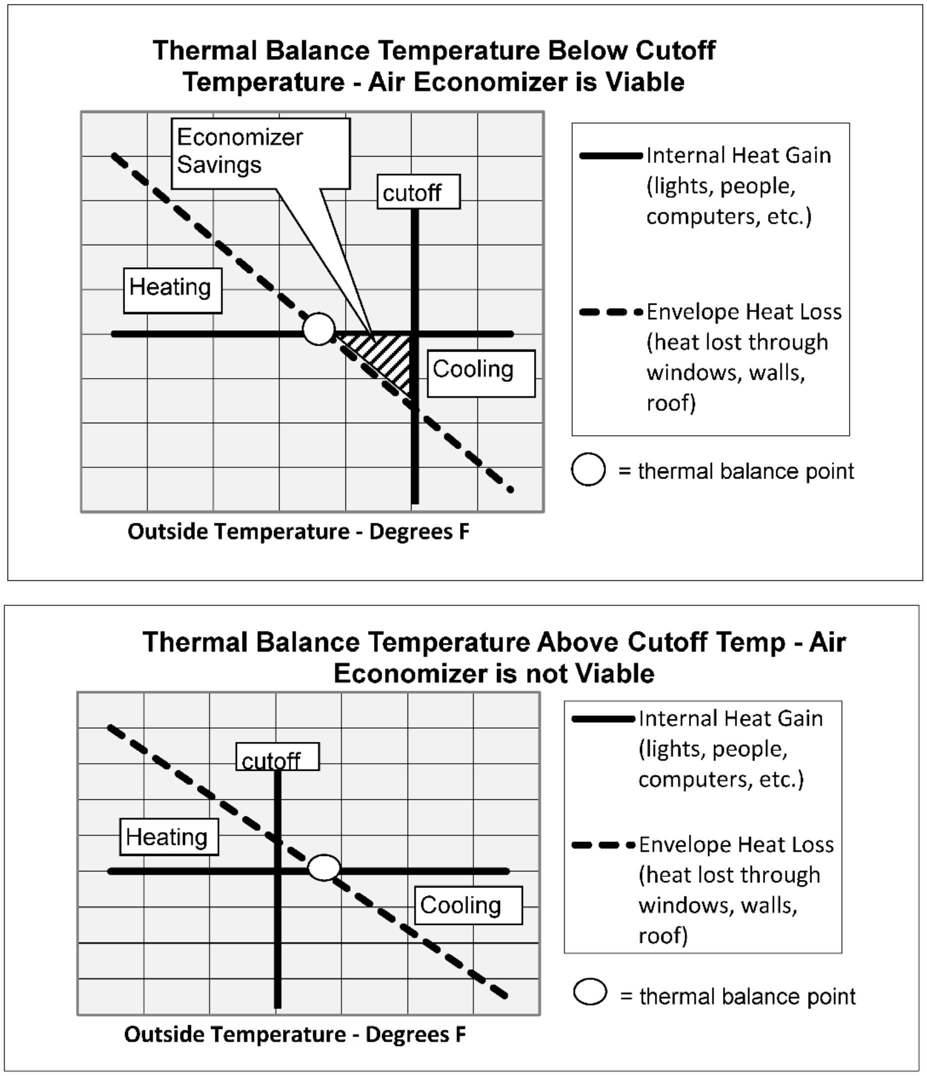

Figure 2. HVAC Air Economizer Value Impact from Building Balance Temperature

'Cutoff' refers to the economizer controls that 'give up' free cooing when the air is not cool enough to work, i.e. we cannot expect to cool a 70F room with 80F air. When the zone balance temperature served by its respective AC unit is below the economizer cutoff and needs cooling, that cooling can be from the economizer with the compressor off, aka 'free cooling'.

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Table 1. Common Thermal Balance Temperatures if No Other Data is Available

Based on balance of internal gains, envelope, and ventilation in a variety of facilities visited. Use table values if no other analytic data is available to be more accurate. Rough description, with expected accuracy as 70% confident.

It is not uncommon to have different values of balance temperature for heating and cooling. This can occur naturally when the indoor thermostat settings are different for heating and cooling (known as dead band). It can also occur in buildings with complex HVAC systems with overlapping heat/cool characteristics.

For the purposes of this estimating an air economizer value, focus on the **cooling** balance temperature in the table.

Building Type	Guideline Balance Temp Heat / Cooling degF	Notes below the heating #, heater runs above the cooling #, cooling unit runs
Apartments, Condominiums, Hotel Guest Rooms (residential)	65 heating/65 cooling 65 heating/60 cooling 70 heating/70 cooling	Unitary HVAC Central heat/cool (boiler + chiller) Primarily geriatric guests, who like it warmer
Church	65 heating/65 cooling 65 heating/55 cooling	Unitary HVAC Central heat/cool (boiler + chiller)
Office building, full, snug and busy, no data center, incl. medical office building, bank	60 heating/60 cooling 60 heating/50 cooling	Unitary HVAC Central heat/cool (boiler + chiller) If an area is a formal data center it will skew the overall balance temperature down
Education classroom building, lots of ventilation and glass	65 heating/65 cooling 65 heating/55 cooling	Unitary HVAC Central heat/cool (boiler + chiller)
Retail, lots of light	60 heating/60 cooling 65 heating/55 cooling	Unitary HVAC Central heat/cool (boiler + chiller)
Commercial kitchen metered by itself, heavy ventilation	45 heating/50 cooling	Unitary HVAC
Restaurant building that has kitchen + dining on same meter	50 heating/60 cooling	Unitary HVAC
Doctor office	60 heating/65 cooling	Unitary HVAC
Outpatient surgery clinic	NA	Heavy reheat, simple analysis does not do well
Hospital	NA	Heavy reheat, simple analysis does not do well
Warehouse with minimal lights, that is heated to 50F, not cooled	50 heating/ --	Unitary HVAC
Warehouse heat/cooled to 70F	65 heating/65 cooling	Unitary HVAC
Generic category: Low internal loads + avg envelope	65 heating/65 cooling	Such as: Parts assembly sit-down work, parts distribution, bench test work, warehouse at 70F, leasing office for apartments and 'common areas', tax preparation, PC repair
Generic category Moderate internal loads + avg envelope	50 heating/55 cooling	Such as: Mfg with a mix of assembly and storage (low energy density) and clean room/air compressor / plating work (high energy density), moderate ventilation rate
Generic category High internal loads and average envelope	40 heating/50 cooling	Such as: Mfg with ovens, boiler, plating, metalworking, compressed air, in higher proportion than assembly and storage

Air Economizer Control Types

Standard Economizer Operation

Standard economizer control is simple and reliable. Below some outside air temperature, often 55 degrees F, the economizer takes over the task of providing cooling. That is to say, when there is a call for cooling, it either comes from conventional equipment or from outside air, depending on how cold it is. Note that this control method is one or the other: either mechanical cooling or economizer cooling. The compressors turn off (energy savings) and the return/outside air dampers modulate to create cool outside air for free. The “55 degree” value is a convenient and forgiving choice because, regardless of relative humidity, 55F will not be a source of moisture problems in most buildings. Truth is, as long as it’s fairly dry outside, free cooling with outside air is viable at temperatures above 55F. Of course, when bringing in outside air for cooling, an equal amount of building air needs to be removed from the building. Relief dampers, exhaust fans, and return fans are used to expel the warm air during economizer mode.

Extended Economizer Operation

At 55 degrees outside air (OA), the moisture content of that air doesn’t matter, but above 55 degrees OA, the air ***may or may not be suitable*** for use in free cooling – depending upon its moisture content. The air in Colorado is usually, although not always, suitable for use at temperatures up to 65 degrees.

For extended economizer operation, the ***compressors run in conjunction with the free cooling dampers.*** Below ~55F, the compressors are off as usual, but above this, rather than give completely up and go back to all mechanical cooling, this method lets air, still cooler than indoors, to help. By expelling the building ‘return’ air and replacing it with outside air, this acts to lower the heat content of the air stream entering the mechanical cooling unit coil. A maximum of 65 degrees is suggested for this extended operation (where compressors are on and outside air damper is full open), and sometimes it is lowered. When the outside air moisture level is higher than indoor humidity design values, either a dehumidification load is incurred (eroding savings) or it becomes uncomfortable (complaints). The extended economizer cut off point is determined from dew point temperature which ultimately reflects a final indoor relative humidity (and rH strongly affects comfort). **Table 2** shows a few representative indoor temperature/ relative humidity combinations and the associated dew point temperature. A reasonable cut off temperature would be a maximum 50F dew point.

Dew point can be measured directly or calculated from outdoor temperature and relative humidity. Dewpoint measurement as well as ‘enthalpy’ measurement used to decide if the outside air is less costly to condition than return air, are both fickle. The math is clear, but the instruments are notorious for drifting and because of this, successful extended economizer operation is usually a combination of frequent calibration or conservative settings, so the instrument errors are on the safe side of comfort.

Table 2. Suggested Maximum Outside Air Dew Point for use in Extended Air Economizer Free Cooling

Values based on maximum resulting indoor relative humidity of 40% at final indoor air temperature with 100% outside air. Increasing OA dew point limit will increase economizer hours but will also increase indoor relative humidity. 50F max dew point is suggested

Dp=dew point in degrees F.

Inside Final Conditions	Outside Air Max Dew Point Temp
72F, 40% rH	47F dp
72F, 50% rH	52F dp
74F, 40% rH	48F dp
74F, 50% rH	54F dp

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

By raising the cut-off point for economizer use, savings increase which is attractive. To capture these savings, some additional investment in controls and system attention are required, such as calibration. Another approach for enabling extended economizers uses recommendations based on statistics that say, for example, in Colorado Springs it is 'usually OK to operate in extended economizer mode up to 62F outside air (dry bulb) since it is 'usually' dry. This allows simpler 'plain dry bulb' controls, just bear in mind on those few moist days it can get muggy inside.

'Watch-Outs' for Air-Economizers

Building pressure. Economizer dampers moving around can affect building pressure. If not properly specified or controlled, you may experience problems like the building front doors standing open, or feeling a "vacuum" on the doors, making them hard to open. In extreme cases, you may experience ceiling tiles lifting. If any of this is happening, it can usually be improved with control adjustments, however if there is no return fan or a power exhaust the use of air economizer will be limited to the extent the building air can find its way out. If the building routinely becomes "negative" (the vacuum effect) this is a particular concern in winter, since it is then possible for pipes to freeze if located near a perimeter – depending on where the cold air finds a way inside.

Freezing. For buildings with low thermal break even points, using very cold air for cooling requires that it be 'mixed' with the return air, and blended to make a reasonable air delivery temperature. The colder the air gets, the more it tends to settle to the bottom by its density. This is called 'stratification' and can cause freezing damage if cooling or heating is done with water, or nuisance tripping of freeze protection controls. If your system uses an air economizer in very cold weather, some method of mechanically mixing the air streams will be required to avoid these troubles.

Controls or damper troubles. Economizer controls that come with packaged rooftop air conditioners need proper care just like any other controls. When neglected, it is common to find the economizer feature not operating properly after 5 years or so….which means the savings have stopped. Incorporating an economizer checkup along with other annual service work will help assure the economizer is working as intended.

- Scenario: When the economizer controls or dampers quit, not only is there a loss of free cooling savings but regular operation can become less efficient – consider an economizer actuator that has failed when 90% open and it stays there. The controls command the damper back to minimum position in cooling and heating season and to be full closed when off, but it stays at 90% open. This condition will increase heating and cooling costs from all the raw outside air it brings in.

Suggested check items for economizers:

- Correct temperature where economizer mode becomes active upon a call for cooling
- Correct temperature where compressor is locked out
- Dampers modulate smoothly to maintain supply air set point
- Air relief devices function properly to maintain building pressure during economizer mode
- Outside air and relief dampers close fully, and return air damper opens fully, when the unit is shut off
- When operating but not in economizer mode, proper minimum outside air setting is used for ventilation
- Correct outside air temperature calibration
- For extended economizer: correct enthalpy sensor calibration

Approximate Economizer Savings

See **Table 3**, with associated notes.

Example use of the table:

Site 1: A commercial business that uses air conditioning is operated 6a-6p daily. The balance temperature has been estimated at 50F.

Standard economizer savings = 3% of annual cooling energy

Extended economizer savings = 15% of annual cooling energy

Site 2: A manufacturing company that uses air conditioning is operated 8760 hours per year. The balance temperature has been estimated at 45F.

Standard economizer savings = 12% of annual cooling energy

Extended economizer savings = 30% of annual cooling energy

Table 3. Approximate Savings from Air Economizer, by Climate Zone. (percent of annual cooling energy)

Source: Commercial Energy Auditing Reference Handbook, 3e Doty,S., Fairmont Press.

Percent of Cooling Load Removed by Economizer

6a-6p 4380 hours

Zone	Balance temp, F ->	Standard 65	Standard 60	Standard 55	Standard 50	Standard 45	Standard 40	Extended 65	Extended 60	Extended 55	Extended 50	Extended 45	Extended 40
1A	Miami, FL	0	0	0	0	1	1	0	0	1	2	2	3
2A	Houston, TX	0	0	0	1	2	4	0	1	3	5	7	9
2B	Phoenix, AZ	0	0	0	1	4	6	0	1	3	7	10	12
3A	Memphis, TN	0	0	0	2	4	7	0	2	4	8	12	15
3B	El Paso, TX	0	0	0	2	4	7	0	1	4	8	12	15
3C	San Francisco,CA	0	0	0	11	20	26	0	13	27	42	50	55
4A	Baltimore, MD	0	0	0	2	6	10	0	2	6	10	15	20
4B	Albuquerque, NM	0	0	0	3	6	11	0	2	5	10	15	20
4C	Salem, OR	0	0	0	7	15	23	0	5	14	24	34	42
5A	Chicago, IL	0	0	0	3	6	10	0	2	6	11	16	20
5B	Boise, ID	0	0	0	4	10	17	0	3	7	14	22	28
5B	Colorado Spgs, CO	0	0	0	3	8	13	0	3	8	15	21	27
6A	Burlington, VT	0	0	0	4	9	14	0	4	10	18	24	29
6B	Helena, MT	0	0	0	4	10	17	0	4	11	20	27	34
7	Duluth, MN	0	0	0	6	14	22	0	7	15	25	34	41
8	Fairbanks, AK	0	0	0	11	21	30	0	10	21	36	46	53

8760 hours

Zone	Balance temp, F ->	Standard 65	Standard 60	Standard 55	Standard 50	Standard 45	Standard 40	Extended 65	Extended 60	Extended 55	Extended 50	Extended 45	Extended 40
1A	Miami, FL	0	0	0	0	1	1	0	1	1	2	3	4
2A	Houston, TX	0	0	0	1	3	5	0	2	4	7	9	12
2B	Phoenix, AZ	0	0	0	2	5	7	0	1	4	8	12	16
3A	Memphis, TN	0	0	0	2	5	9	0	2	5	10	14	18
3B	El Paso, TX	0	0	0	2	6	9	0	2	5	9	14	18
3C	San Francisco,CA	0	0	0	20	34	41	0	15	33	54	64	69
4A	Baltimore, MD	0	0	0	3	7	11	0	3	8	13	19	24
4B	Albuquerque, NM	0	0	0	3	8	12	0	3	8	14	20	25
4C	Salem, OR	0	0	0	10	22	32	0	6	17	32	43	52
5A	Chicago, IL	0	0	0	4	8	13	0	4	9	16	22	27
5B	Boise, ID	0	0	0	5	12	19	0	4	9	17	26	33
5B	Colorado Spgs, CO	0	0	0	5	12	19	0	5	12	22	30	37
6A	Burlington, VT	0	0	0	5	12	18	0	6	13	22	30	36
6B	Helena, MT	0	0	0	6	14	22	0	5	14	25	34	41
7	Duluth, MN	0	0	0	9	19	28	0	8	18	31	42	50
8	Fairbanks, AK	0	0	0	13	24	34	0	11	23	39	49	57

Notes for table:

1. "Standard economizer" cools with mechanical cooling or economizer, but not both
2. "Extended economizer" operates above the compressor cut out point, with the compressor as supplement in addition to full outside air, when conditions are favorable
3. Load is max at max dry bulb and zero at balance temperature
4. Economizer is available between set points of "cut in and cut out". For this table:
   For standard economizer, cut in is 55F and cut-out is 0F
   For extended economizer, cut in is 65F and cut-out is 0F
5. Compressor off below 55F for standard and extended economizer
6. if extended, economizer operation above the compressor cut in value is pro rated (shared) Pro-ration assumes 75F return air, 55F supply air. Model assumes that when outside air is 65F, outside air does 1/2 of the work, and the compressor does 1/2

Circled values correspond to the scenario example on the prior page.