Heating With Steam Efficiently

Is steam overdue to be the next hot choice for K-12 heating? The author lays out the case for getting steamed, from its high potential energy to equipment that a steam-based system may be able to forego altogether. Special attention is also paid to components that protect coils from collapse or freezing, ranging from steam traps to auxiliary vents, vacuum breakers, and beyond.

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In designing for heat transfer in HVAC systems, steam is an effective and efficient medium. However, steam is often overlooked for hot water, notably in the K-12 market. While there are historical problems with traditional steam heating methods, these problems, if identified and considered in the design process, can be overcome.

A majority of the energy used in education buildings is used for space heating; a majority of that is provided by boilers[1]. The trend in new school construction is toward hot water heating. However, steam has five to six times the potential energy of an equivalent mass of hot water and is easier to control. Considering the financial crunch that many school systems find themselves in between increasing energy costs and decreasing O&M budgets, the efficiency and simplicity of steam merit consideration.

Compared to hot water, there are several advantages to steam. Due to higher energy content per mass, the required heat transfer area is smaller, heat coefficients are higher, and distribution pipes and necessary plant sizes are smaller. Rather than costly circulating pumps and the relatively larger components needed for hot water systems, steam is distributed and controlled through pressure differentials. However, utilizing the heat of steam requires it to be condensed, which can be troublesome. In fact, condensate and its removal are the source of most of the problems associated with steam heating. To effectively take advantage of steam's higher energy content and flexibility, the byproduct, condensate, must be controlled and utilized so as not to hamper heat transfer, or, worse, lead to frozen or damaged coils.

STEAM AND THE NON-CONDENSABLES

In the boiler, non-compressible water becomes the compressible gas: steam. The higher the steam pressure, the higher the sensible heat and the lower the latent heat content. As pressure increases and latent heat decreases, volume in cubic feet per pound decreases. Therefore, we can generate steam at high pressure and distribute it with smaller piping. However, a higher latent heat is desirable at the source, so we reduce the pressure before the heating coil

Table 3: Properties of Saturated Steam

Gauge Pressure PSIG	Temperature °F	Heat in Btu/lb. Sensible	Latent	Total	Specific Volume Cu. ft. per lb.	Gauge Pressure PSIG	Temperature °F	Heat in Btu/lb. Sensible	Latent	Total	Specific Volume Cu. ft. per lb.
25 (IN VAC.)	134	102	1017	1119	142.0	185	382	355	843	1198	2.29
20 (IN VAC.)	162	129	1001	1130	73.9	190	384	358	841	1199	2.24
15 (IN VAC.)	179	147	990	1137	51.3	195	386	360	839	1199	2.19
10 (IN VAC.)	192	160	982	1142	39.4	200	388	362	837	1199	2.14
5 (IN VAC.)	203	171	976	1147	31.8	205	390	364	836	1200	2.09
0	212	180	970	1150	26.8	210	392	366	834	1200	2.05
1	215	183	968	1151	25.2	215	394	368	832	1200	2.00
2	219	187	966	1153	23.5	220	396	370	830	1200	1.96
3	222	190	964	1154	22.3	225	397	372	828	1200	1.92
4	224	192	962	1154	21.4	230	399	374	827	1201	1.89
5	227	195	960	1155	20.1	235	401	376	825	1201	1.85
6	230	198	959	1157	19.4	240	403	378	823	1201	1.81
7	232	200	957	1157	18.7	245	404	380	822	1202	1.78
8	233	201	956	1157	18.4	250	406	382	820	1202	1.75
9	237	205	954	1159	17.1	255	408	383	819	1202	1.72
10	239	207	953	1160	16.5	260	409	385	817	1202	1.69
12	244	212	949	1161	15.3	265	411	387	815	1202	1.66
14	248	216	947	1163	14.3	270	413	389	814	1203	1.63
16	252	220	944	1164	13.4	275	414	391	812	1203	1.60
18	256	224	941	1165	12.6	280	416	392	811	1203	1.57
20	259	227	939	1166	11.9	285	417	394	809	1203	1.55
22	262	230	937	1167	11.3	290	418	395	808	1203	1.53
24	265	233	934	1167	10.8	295	420	397	806	1203	1.49
26	268	236	933	1169	10.3	300	421	398	805	1203	1.47
28	271	239	930	1169	9.85	305	423	400	803	1203	1.45
30	274	243	929	1172	9.46	310	425	402	802	1204	1.43
32	277	246	927	1173	9.10	315	426	404	800	1204	1.41
34	279	248	925	1173	8.75	320	427	405	799	1204	1.38
36	282	251	923	1174	8.42	325	429	407	797	1204	1.36
38	284	253	922	1175	8.08	330	430	408	796	1204	1.34
40	286	256	920	1176	7.82	335	432	410	794	1204	1.33
42	289	258	918	1176	7.57	340	433	411	793	1204	1.31
44	291	260	917	1177	7.31	345	434	413	791	1204	1.29
46	293	262	915	1177	7.14	350	435	414	790	1204	1.28
48	295	264	914	1178	6.94	355	437	416	789	1205	1.26
50	298	267	912	1179	6.68	360	438	417	788	1205	1.24
55	300	271	909	1180	6.27	365	440	419	786	1205	1.22
60	307	277	906	1183	5.84	370	441	420	785	1205	1.20
65	312	282	901	1183	5.49	375	442	421	784	1205	1.19
70	316	286	898	1184	5.18	380	443	422	783	1205	1.18
75	320	290	895	1185	4.91	385	445	424	781	1205	1.16
80	324	294	891	1185	4.67	390	446	425	780	1205	1.14
85	328	298	889	1187	4.44	395	447	427	778	1205	1.13
90	331	302	886	1188	4.24	400	448	428	777	1205	1.12
95	335	305	883	1188	4.05	450	460	439	766	1205	1.00
100	338	309	880	1189	3.89	500	470	453	751	1204	.89
105	341	312	878	1190	3.74	550	479	464	740	1204	.82
110	344	316	875	1191	3.59	600	489	473	730	1203	.75
115	347	319	873	1192	3.46	650	497	483	719	1202	.69
120	350	322	871	1193	3.34	700	505	491	710	1201	.64
125	353	325	868	1193	3.23	750	513	504	696	1200	.60
130	356	328	866	1194	3.12	800	520	512	686	1198	.56
135	358	330	864	1194	3.02	900	534	529	666	1195	.49
140	361	333	861	1194	2.92	1000	546	544	647	1191	.44
145	363	336	859	1195	2.84	1250	574	580	600	1180	.34
150	366	339	857	1196	2.74	1500	597	610	557	1167	.23
155	368	341	855	1196	2.68	1750	618	642	509	1151	.22
160	371	344	853	1197	2.60	2000	636	672	462	1134	.19
165	373	346	851	1197	2.54	2250	654	701	413	1114	.16
170	375	248	849	1197	2.47	2500	669	733	358	1091	.13
175	377	351	847	1198	2.41	2750	683	764	295	1059	.11
180	380	353	845	1198	2.34	3000	696	804	213	1017	.08

TABLE 1. The properties of saturated steam (steam tables).

to take full advantage of steam's heating potential. The pressure differential across the pressure reducing valve and the pressure drop from the steam moving through the distribution pipes and condensing in the coil ensures flow.

Since steam gives up its energy through condensing, known as the process of latent heat, it provides heat at a constant temperature. This is a significant benefit. It makes for a more efficient, easier to control process. As compared to hot water, steam responds much quicker to changes in demand. However, as noted, the condensate byproduct can be problematic if not handled correctly.

The latent heat process in the steam coil, or other heat exchanger, results in the formation of condensate. A properly applied steam trap is the appropriate method for condensate removal. Steam traps serve as the dividing line in the system, with, ideally, steam on the inlet side and condensate at the discharge. While in practice and, sometimes by design, there may be varying amounts of condensate on the inlet side of the trap, upstream steam pressure should move all condensate through the trap, with little or no steam passing through. Steam traps are sized according to condensate load. The formula for determining condensate load is as follows:

$$\text{lb/hr condensate} = \frac{\text{cfm} \times 1.08 \times \Delta T}{L}$$

Where:

cfm = Air flow in cubic feet per minute;
ΔT = Temperature difference across the coil; and
L = Latent heat of steam Btu/lb.

The latent heat of steam at any given pressure can be found in the steam tables (Table 1). Calculate condensate load based on the coil's highest operating pressure. A good rule of thumb for steam traps is to use a 2:1 safety factor at 1/2 in. psi pressure differential for 0 to 15 psig steam. On systems utilizing 16 to 30 psig, a safety factor of 2:1 at 2 psi pressure differential should be used. For systems operating above 30 psig, a safety factor of 3:1 at half the maximum pressure differential across the trap should be used.

While the science of steam trap application is a subject all to itself, it can be noted that in nearly all HVAC applications, a float and thermostatic steam trap, sized for the appropriate safety factor, will work well. The float and thermostatic steam trap is fairly resistant to dirt, works well under modulating loads, and does a great job of handling the other potential trouble spot, air.

Air can be just as insidious and potentially dangerous as condensate to the proper operation of a steam heating system. However, in a properly designed system, air can be controlled and for the most part eliminated. Air in a system cannot be totally avoided. It is a natural byproduct of steam generation. It is present during equipment startup and is often found in feedwater. Air and other non-condensable gases can serve as insulators between the steam and the coil surface, thereby decreasing efficiency. Worse, dissolved carbon dioxide and oxygen in condensate form a corrosive carbonic acid that can eat through pipes and tubes. Therefore, it is just as important to remove the air from the system as it is the condensate.

While the thermostatic air vents that are integral to float and thermostatic steam traps work well to remove air and other non-condensables, it is advisable to install auxiliary air vents with steam coils. The recommended location for an auxiliary air vent is on the condensate line at the top of a riser located 12 to 18 in. above the bottom of the coil, before the steam trap. In systems that operate at pressures lower than

15 psig the outlet of the air vent should be piped to the condensate return (Figure 1).

All steam coils should have a vacuum breaker installed. Control valves, isolation valves, and the process of shutting the system down can induce situations wherein coils operate at subatmospheric pressures. To prevent coil collapse and keep condensate moving, vacuum breakers should be utilized. Vacuum breakers can be installed in the piping immediately before the coil or in the condensate line before the steam trap. Whenever steam supply pressure falls below atmospheric the vacuum breaker will open, inducing air into the system and breaking the vacuum. While this may seem counterintuitive, considering the dangers of air in the system, it is much more important to keep everything moving, avoid a potential coil collapse and or frozen coil, and deal with the air through venting.

THE STEAM COIL

When heating with steam, as with any other medium, some part of the system must be manipulated or modulated to control setpoint temperature. The most common way of doing this with steam has been to modulate flow with a control valve. On steam coils this presents a unique difficulty. Since steam's potential is best optimized at a low pressure, most steam heating systems are designed for 30 to 15 psig or lower. Once the heated space begins to reach setpoint, the control valve will modulate down, lowering steam flow through the valve. Eventually the supply pressure may be reduced

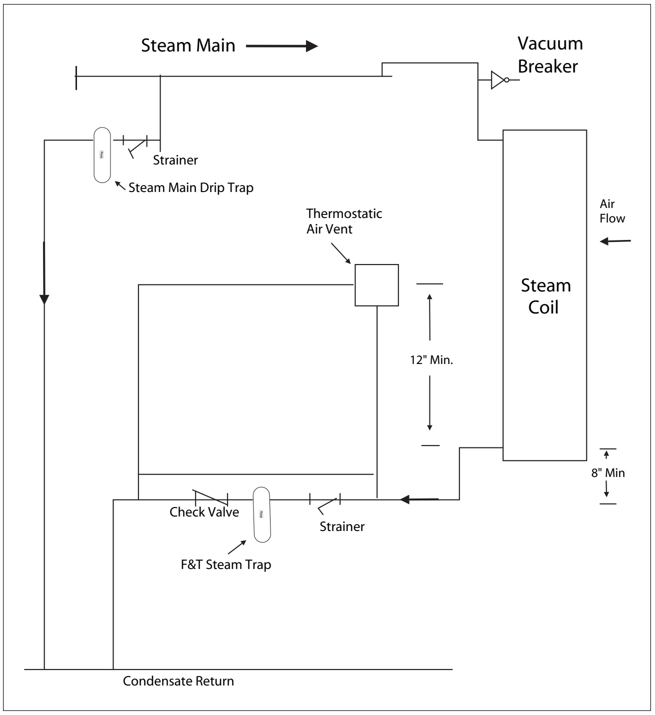

FIGURE 1. Recommended coil piping.

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to operating either at subatmospheric pressures or below the back pressure in the condensate return line. At this point, the coil is in a condition of stall and condensate will begin to back up into the coil.

It is at the point of coil stall that the major problems of heating with steam begin. Condensate that backs up into, and stays in, the coil is subject to freezing. Of course a vacuum breaker will break the vacuum and force the condensate out of the coil, under atmospheric pressure. But the condensate system must be operating at a back pressure that is below atmospheric and utilizing gravity to drain all the condensate from the coil. In most cases this is not enough to remove all the condensate. And any condensate left is subject to freezing.

Additionally, the cracking of the vacuum breaker induces air into the system, which has corrosive and insulating effects. This is not to say that vacuum breakers are not worth using, nor that air can be totally avoided. That is generally not the case, and, as stated above, the air can be dealt with. Rather, the point is that it is better to avoid coil stall altogether, and stick by the maxim of efficient steam coil heating, keeping the fluids moving[2].

An alternative approach that does not require the modulation of steam flow, and has met with some degree of success, is the built-up face and bypass system used in some air handlers. This type of system employs a bypass system with a set of dampers to direct incoming air either over the coil or through the bypass depending on demand. This type of system provides a better alternative, because the airflow over the coil is modulated for temperature control and steam flow is kept constant. Constant steam flow keeps the condensate and non-condensables moving and out of the coil. Airflow is directed by the dampers, which are controlled based on leaving air temperature. The downside to these systems is that they require a considerable amount of physical space in an air handler, have variable static pressure drops, and often have considerable temperature overshoot in the bypass mode. While efficiency is gained on the steam side, it is compromised to some degree on the air side[3].

THE INTEGRAL FACE AND BYPASS STEAM COIL

An efficient way to capture the energy benefits of steam and keep the condensate moving is with the integral face and bypass steam coil. As the name implies, the face and bypass dampers in the integral face and bypass steam coil are integral to the coil. This results in a compact and efficient system. Steam flow is kept at a constant,

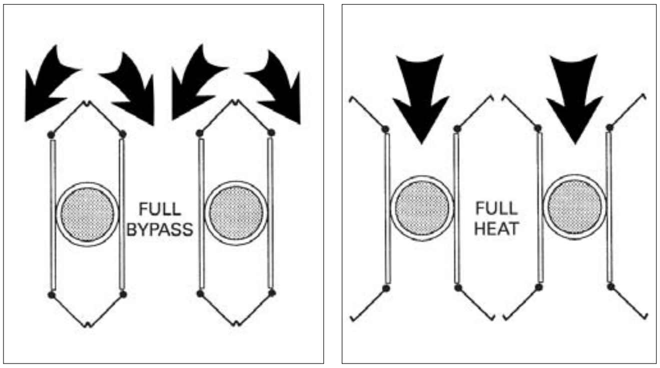

FIGURE 2. Cross-section of integral face and bypass coils.

and the leaving air temperature is maintained by proportioning the entering air through the multiple heating and bypass chambers in the coil with the dampers.

As noted in Figure 2, the dampers operate like clamshell dampers in that they enclose the coil area when in full bypass mode and block off the bypass channels when in the full face mode. In an actual heating operation, they are usually somewhere in between, providing the correct proportioning of air to maintain the necessary leaving air temperature. An airstream thermostat senses the leaving air temperature and signals the modulating motors which control the operation of the dampers. This provides a constant discharge air temperature, regardless of variations in entering air temperature.

The benefit to an integral face and bypass coil over a built-up face and bypass air handler is in space utilization and operating efficiency. The integral face and bypass coil takes up less space in an air handler. Additionally, integral face and bypass coils can be installed in ductwork as preheat or reheat coils. Airflow and pressure drop are at a constant volume, regardless of damper positioning, usually 0.15 in. wc or less. In the complete bypass mode temperature override is minimal, generally 3° to 4°F maximum. No further controls, other than a vented steam trap, are needed. For further freeze protection, a freezestat can be used which will place the unit in the full bypass mode upon the loss of saturated steam temperature in the tubes.

COMPLETING THE LOOP

Getting the steam to, and all the condensate out of, the coil efficiently is the toughest part of the steam heating job. Continually doing so will result in an efficient system. Thus, to complete the loop, and further protect the coil from being flooded, the condensate has to be returned to the plant. Like any other component of steam engineering, condensate management is a science all its own, and much can be said about it. Without getting too far a-field, we will cover the basics of condensate management, especially as they apply to HVAC applications. After all the work accomplished by the steam in the heating coil, as much as 25% of the energy originally produced in the boiler is still available in the condensate. In terms of efficiency, we want to get as much of that energy as possible back to the boiler. In terms of system performance, we want to do it the best way.

Recaptured condensate is essentially boiler feed water that does not have to be treated or heated. Condensate at 212° has 180 Btu/lb of sensible heat. In plain and simple terms, this is sensible heat that does not have to be added to boiler feed water that may come in the building at 50° or so. Condensate also retains most of the boiler treatment chemicals used in the system. It only makes sense to return all, or as much condensate as possible, to the boiler. However, it must be done correctly.

One of the most common mistakes made in designing condensate return systems is to size condensate lines based on water flow. Hot condensate discharging out of high-pressure steam traps into low-pressure condensate return lines is subject to flashing. Typically, the amount of flash steam in a condensate system is 10% to 15% by mass. The specific volume of flash steam is 26.8 cubic feet per pound, as compared to .016 cubic feet per pound of water.

Herein lies the problem. Condensate lines sized solely on water flow are insufficient to handle the accompanying flash steam. Condensate lines should be sized to handle two-phase flow by determining the quantity of flash steam inherent in the system, and sizing the return line for velocities between 4,000 and 6,000 ft/min. The line size on the discharge side of steam traps should also be increased to accommodate flash. If the heating coil shares the condensate return system with other steam equipment operating at various pressures, the condensate should be returned to a vented receiver and pumped back to the powerhouse from there[4]. Again, the goal is to keep low pressure in the condensate return system, and to keep it flowing.

APPLICATIONS

Steam has a long history as a heating medium. It has been used most successfully in industrial and institutional applications and to some degree in the K-12 market. Considering the demands of ASHRAE 62, ever-rising energy costs, the increasing pressure on O&M budgets, and the benefits of an efficiently designed steam system, there are good reasons to consider steam heat more often.

Whenever steam supply pressure falls below atmospheric, the vacuum breaker will open, inducing air into the system and breaking the vacuum. While this may seem counterintuitive, considering the dangers of air in the system, it is much more important to keep everything moving and deal with the air through venting.

Many contemporary projects utilize boilers to produce steam, which in turn heats water for a hydronic heating system. Using the steam directly is a better choice. Besides higher heat coefficients, the energy lost in the conversion process can be capitalized by using the steam directly. And, additional savings can be found in the elimination of the heat exchanger and water pumps, the use of smaller distribution pipes, and simpler, more efficient controls. Specific applications such as gymnasiums, dining facilities, and auditoriums which generally require air handlers and large quantities of outside air are especially good candidates for steam heat utilizing integral

Reliability and maintainability are always concerns, especially in the K-12 market where personnel are often stretched thin. This is where the face and bypass steam coil can really pay off. Because of the simplicity and accuracy of the controls, and provided the rest of the system is designed to keep condensate moving, an integral face and bypass coil heating system is relatively trouble-free.

face and bypass steam coils.

Reliability and maintainability are always concerns with mechanical equipment, especially in the K-12 market where maintenance personnel and capabilities are often stretched thin. This is where the face and bypass steam coil can really pay off. Because of the simplicity and accuracy of the controls, and provided the rest of the system is designed to keep condensate moving, an integral face and bypass coil heating system is relatively trouble-free and easy to maintain.

While it is obvious that every heating application is not suited for steam, there are likely many more applications than are currently realized. The economic benefits in terms of equipment costs, energy utilization, and operating maintenance of a properly designed system make steam, one of the world's oldest technologies, still relevant and beneficial in the twenty-first century. **ES**

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