47

Integrated decentralized chilled water systems

Chilled water when applied to air conditioning refrigeration systems is employed as an intermediate heat transfer fluid for the purpose of conveying heat from the space (via a cooling coil) to the refrigeration cycle from which it is normally "pumped" to the higher temperature sink of the outdoor air or an available water source. As technology in chilled water systems developed, it became increasingly evident that in addition to being a thermal conveyor, enabling a physical separation between the load and the source (such that each could be located for the convenient satisfaction of other design parameters), two additional primary advantages emerged:

1) The thermal lag or time constant provided by the inherent storage characteristic of the water provides improvements and simplifications in the control of both the air side apparatus and the refrigeration machinery.

2) When multiple points of cooling or conditioning the air are required, the diversity between these loads can be applied to the refrigeration machinery size and operating modes. This feature results in lower investment in refrigeration and dissipation apparatus and a reduced energy consumption by the refrigeration prime mover.

See growth of central plants

In recent years, the centralization of chilled water refrigeration systems has been seen to grow beyond the lines of a single building, lending to the extended use of central chilled water plants serving shopping centers, campus-type developments for educational institutions, health care facilities, office complexes, and municipal-type plants serving multitudes of commercial customer loads.

In many cases, whether by original planning or for lack thereof, a grouping of buildings such as a college campus, or a single large building, has developed a system of separate chilled water systems serving individual buildings or individual portions of a single building.

The concept discussed herein is a method for integrating these isolated chilled water systems into a single system or "loop" to regain the advantages of the centralized system.

Consider campus as example

Consider, as an example, a hypothetical campus shown in Fig. 47-1. The load quantities represent the full load refrigeration system requirements for each of the ten buildings.

Consider, further, two basic alternative methods for providing for these loads with chilled water systems. First, Serve each the loads from a single chiller located in the respective building. This alternative would require the installation of ten chillers, with a total refrigeration capacity of 2000 tons. This capacity would have to be provided in both the refrigeration prime mover apparatus and heat dissipation apparatus, such as condenser water pumps and cooling towers.

This approach would, under any increments of part load (say, for example, 10 percent load on all buildings) require the operation of all the chillers, each at a greatly reduced load and

---

This chapter was reprinted from *ASHRAE Transactions*, Vol. 82, Part I, 1976 and was originally entitled, "Integrated Decentralized Chilled Water Systems." Appearance of this material in *Energy Engineering and Management for Building Systems* does not necessarily suggest or signify endorsement by the American Society of Heating, Refrigerating or Air-Conditioning Engineers, Inc.

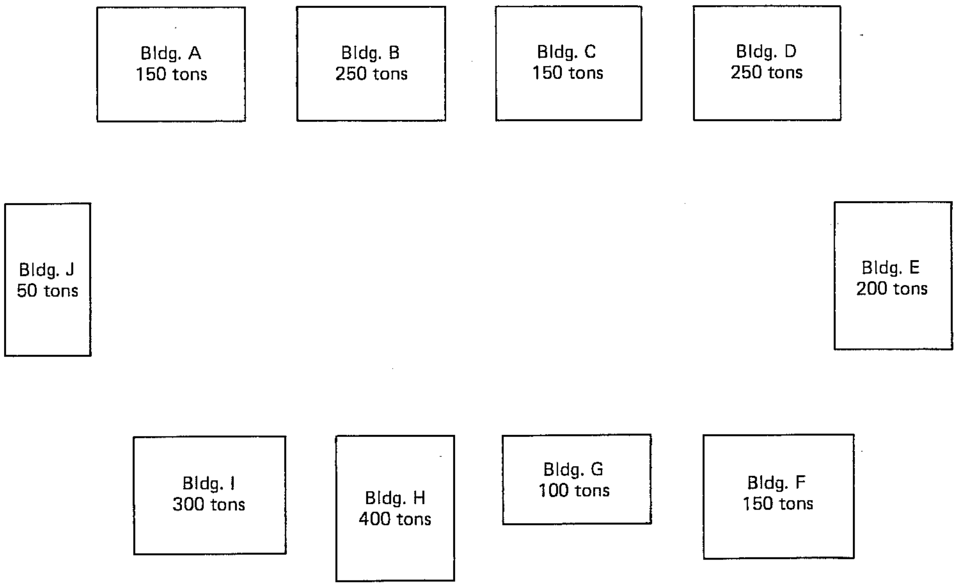

Fig. 47-1. Hypothetical Campus Loads

most additional supplementary equipment at full load. Another disadvantage is that of reliability. Since, in the hypothetical example, each building is provided with one chiller, in the event of a failure of that unit, the building would be without cooling. With current building technology, this degree of reliability in the refrigeration systems is totally untolerable.

The second alternative would be to serve all of the loads from a central chilled water plant. If this were done, the diversity of loads between buildings could be reflected back to the size of the chiller plant. This diversity results from:

1) relationship between time of peak load of buildings resulting from variations in use, functions, architectural design, orientation, etc;

2) shifting of occupants on campus from one space to another.

The studies of numerous campus cooling systems reveal that a building/system diversity of 0.70 applied to the sum of the building loads is fairly representative. Thus, a central plant for this campus could be provided with $2000 \times 0.7 = 1400$ tons, resulting in a reduction from the individual systems of some 600 tons of refrigeration and heat dissipation apparatus. The chilled water distribution system required would possibly partially offset this monetary savings. The distribution system would require a basic pipe size capable of conveying the entire 1400 tons as a minimum, and the primary pumping circuit would require the energy input to circulate the 1400 tons of cooling capacity throughout the campus.

The lack of individual building reliability realized with the individual systems, and the numerous hours of operation of multiple machinery, each at greatly reduced loads, are effectively resolved with well-directed design of the central plant. Both parameters are satisfied, in most cases, by proper selection of the machine modules or sizes, selected to match the part load profile of the integrated system. Often, an acceptable degree of reliability can be achieved without the investment burden of excess capacity. Matching the module size to minimum number of hours of operation will generally provide a statistical probability of coincident failure during those few "peak load" hours well within the range normally required in comfort cooling.

Integrated system explained

The integrated decentralized chilled water system concept is an attempt at achieving a

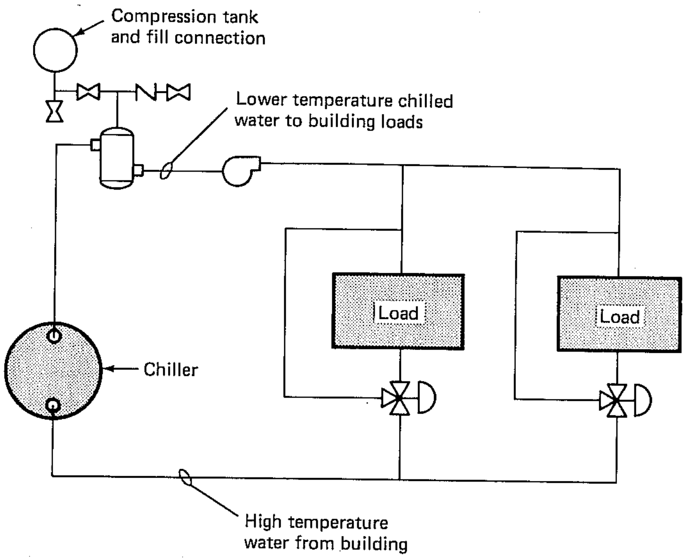

Fig. 47-2. Typical Simplified Building System

majority of the advantages of both the decentralized and the central plant approaches. The concept is to connect all the building systems into a common pipe or pumped loop. If a typical flow diagram of a building system is as shown in Fig. 47-2, the concept of the integrated decentralized loop is to tie the load into the integrated "system" and provide the capacity of the chiller to the system. For this building, this connection would be made as shown in Fig. 47-3. The development of the loop for the hypothetical campus would simply extend this methodology throughout the campus to all ten buildings, resulting in the flow diagram shown in Fig. 47-4. Although it may not be immediately evident that full load advantages exist, consider that if the campus diversity is 70 percent, Fig. 47-4 shows an integrated system with an integrated capacity of 1400 tons and a machinery capacity of 2000 tons.

Since all the loads and sources are con-

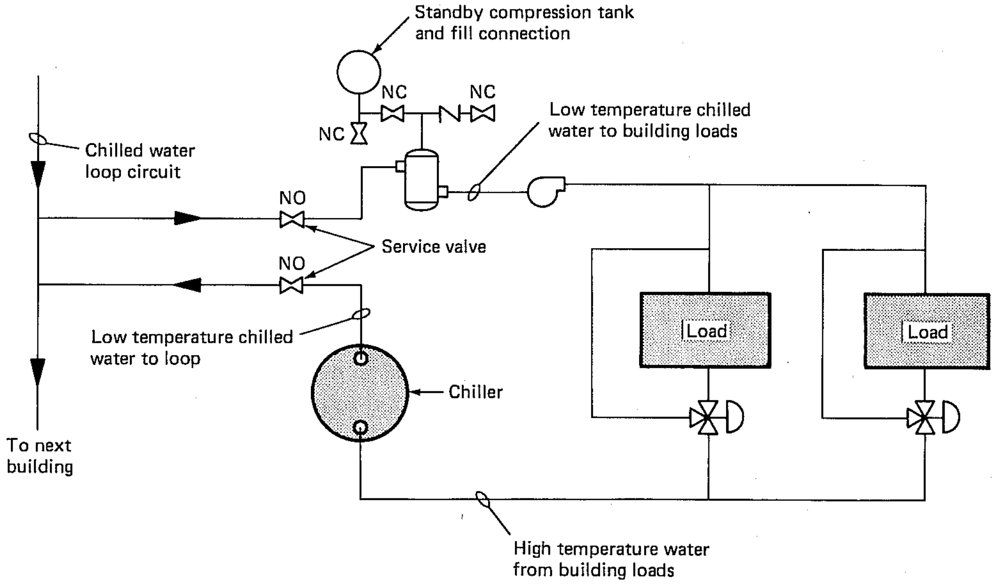

Fig. 47-3. Connection of Building System to Loop main

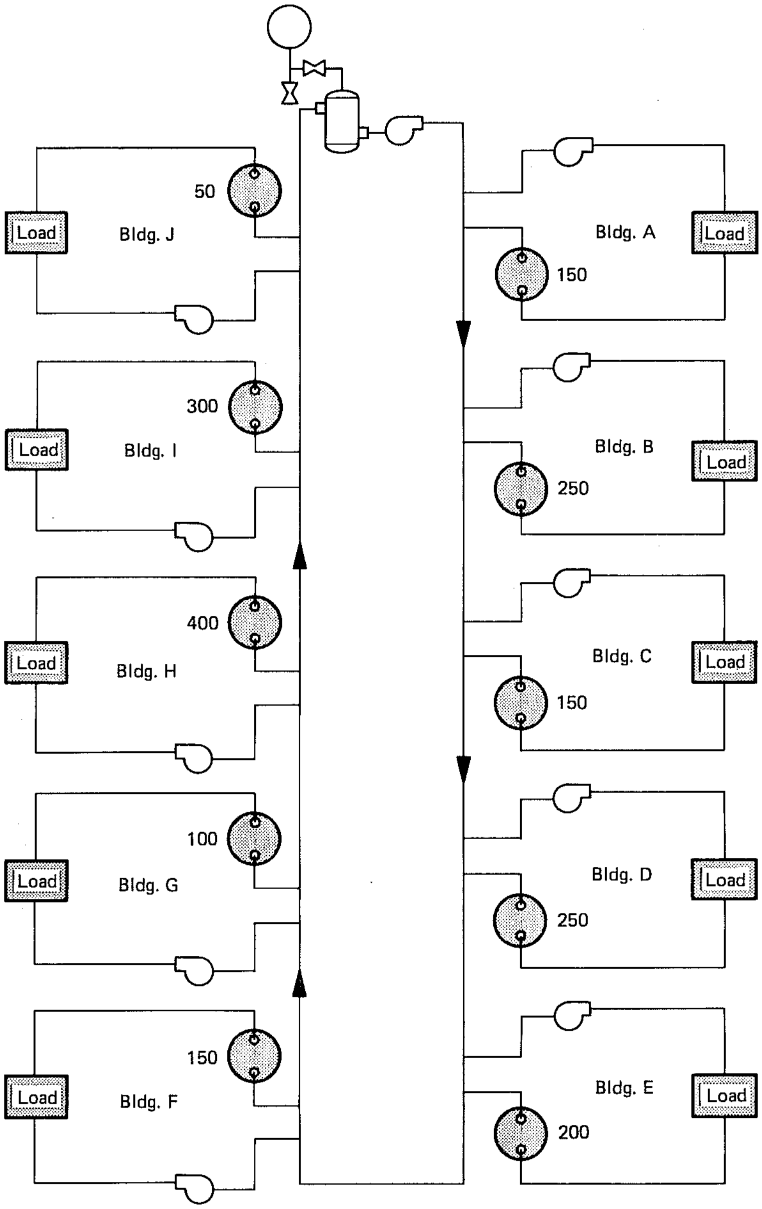

Fig. 47-4. The Integrated Loop

nected in series along the "closed loop" the first step in analyzing the loop dynamics is to perform a temperature gradient analysis. Such a full load loop analysis consists of determining the design coincident load for all of the buildings and the time the coincident design will occur. The results of this analysis in tabular format are shown in Fig. 47-5.

After determining the coincident full load of the connected buildings, the loop design can proceed to selection of the loop size and pumping rate. Note that at this point, assuming the individual systems projected in Fig. 47-1, that we have a singular chilled water system with 2000 tons source capacity and a coincident connected full load of 1400 tons, or a reserve (and "pickup") capacity of 43 percent.

The minimum loop circulating capacity must be matched to the full load circulating

Building	Full load	Coincident diversified load	Chiller capacity	Excess capacity
A	150	50	150	100
B	250	250	250	0
C	150	100	150	50
D	250	100	250	150
E	200	150	200	50
F	150	150	150	0
G	100	50	100	50
H	400	300	400	100
I	300	200	300	100
J	50	50	50	0
Totals	2000	1400	2000	600

Fig. 47-5. Tabular Summary of Loads.

capacity of either the largest load or source. The temperature variation in either increase or decrease along the loop will be:

$$t_l = t_e + \frac{\text{load Btuh}}{(500)(\text{gpm})_{\text{loop}}}$$

or

$$t_l = t_e - \frac{\text{source Btuh}}{(500)(\text{gpm})_{\text{loop}}}.$$

Thus, assuming that all the sources and loads for the campus shown are based upon 12 F, the minimum loop circulating capacity would be dictated by Building H, which would be

$$\text{gpm} = \frac{(400)(12{,}000)}{(500)(12)} = 800 \text{ gpm}.$$

Under maximum or full campus load, then, a temperature gradient around the loop is developed. The starting temperature is assumed as the nominal design or "target" temperature, and the starting point is irrelevant. A temperature *range* for the entering water temperature in each building must be established, or following the preliminary analysis this range is established. If the arbitrary starting point for the temperature analysis is set as the entrance to building A, Fig. 47-6 shows a tabular analysis for the temperature decrement around the loop. Note that in Fig. 47-6, 50 F has been established as the maximum loop temperature. Thus, whenever the temperature would tend to exceed 50 F, the capacity of a chiller is provided. A more descriptive method of projecting this information is with a bar chart which is warped to show the loads as diagonal lines downward and to the right and the sources as vertical lines. Such a chart is projected in Fig. 47-7, showing the same data that appears in tabular form in Fig. 47-6. In the figure, the scales on the left ordinate and the abscissa represent loads and chillers in tons of refrigeration, and the right ordinate scale represents loop temperature. Note that if the loop is connected as shown in the flow diagram or connection diagram (Figs. 47-3 and 47-4), the temperature of the loop for any given building will be equal to that on the diagram "leaving" the chiller. The useful loop temperature is always represented at the tail of a diagonal arrow on Fig. 47-7.

For the example shown and developed thus far, the flow rate was selected as the minimum

Bldg.	Entering temp. °F	Loop less chiller °F	Loop with chiller °F	Loop temp °F	Chiller not running tons
A	44.0	45.5	Off	45.5	150
B	45.5	53.0	45.5	45.5	—
C	45.5	48.5	Off	48.5	150
D	48.5	51.5	44.0	44.0	—
E	44.0	48.5	Off	48.5	200
F	48.5	53.0	48.5	48.5	—
G	48.5	50.0	Off	50.0	100
H	50.0	59.0	47.0	47.0	—
I	47.0	53.0	44.0	44.0	—
J	44.0	45.5	44.0	44.0	—

Fig. 47-6. Full Load Temperature Decrement.

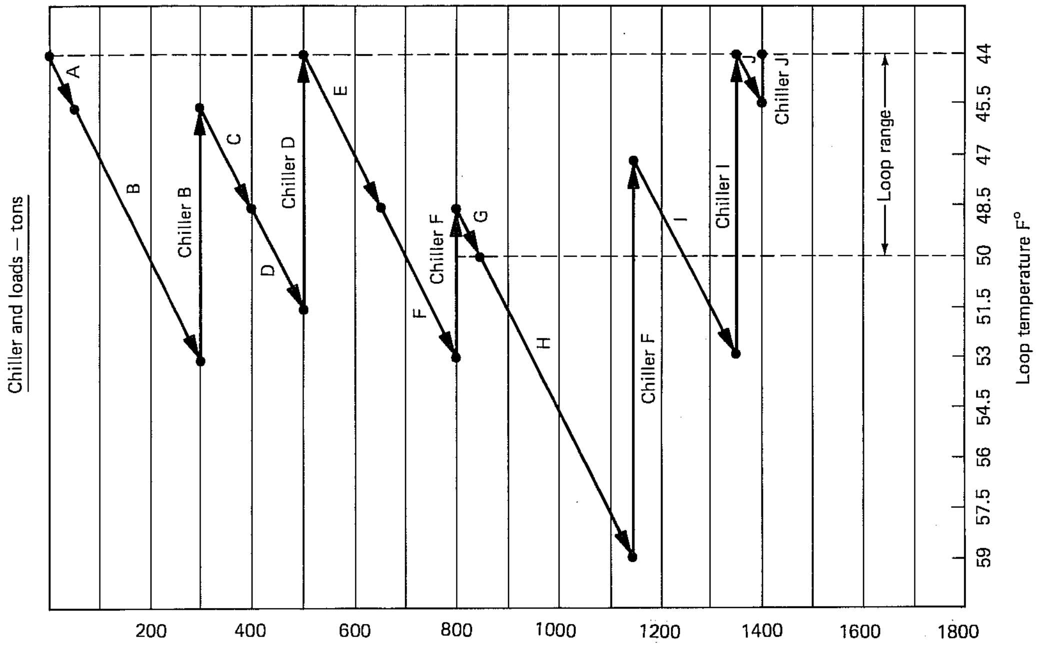

Fig. 47-7. Chiller & Loads Versus Chilled Water Sources.

flow being equal to the flow rate required by the largest load or source connected to the loop. This minimum is rather self-explanatory, since a cursory inspection of the flow diagram will reveal that, at any load, if the loop flow is less than the load or the source, recirculation will occur. The other limit, that of maximum loop flow, is a function of the maximum tolerable building system entering water temperature. The loop range established was 6 F, which was defined by the maximum permissible temperature entering any building, and the nominal design or minimum loop temperature. If a lesser range were desired, (say maximum of 3 F entering any building) the flow rate would simply be determined by the relationship:

$$\frac{\text{gpm}_2}{\text{gpm}_1} = \frac{\text{loop range 1}}{\text{loop range 2}}.$$

Thus, if the specific design requires a maximum entering water temperature to any building of 47 F, the loop flow rate would be:

$$\text{gpm}_2 = \text{gpm}_1 \frac{50\text{-}44}{47\text{-}44}$$

$$= 800 \; \frac{6}{3}$$

$$\text{gpm}_2 = 1600 \text{ gpm}.$$

The reduced load operation enables the remaining machines to be dropped off the line as the loop temperature drops. However, the geographic location of the respective loads and sources imposes a limitation on the minimum number of units that can be operated. It is not within the scope of this chapter to illustrate the entire technique of the part load analysis, but two approaches are suggested, both being an iterative analysis of the thermal dynamics versus the various reduced load conditions:

1) Conduct a series of part load calculations including the various occupancy situations and weather conditions, then simply plot the warped bar chart of Fig. 47-7 (or tabular data of Fig. 47-6) for each identified condition.

2) If a computer program is available which calculates the part load, the loop mathematics can be interfaced with these data to provide

the machine operating hours and ton-hours directly.

Caution must be exercised in using the latter approach since most computer programs do not take into account such variables as control ranges, operating techniques, and machines deadlined for overhaul or service.

Explain elements of control

Control of the integrated loop system can be either by manual start-stop or the logic can be automated. However, due to the inherent decentralized nature of the system, remote monitoring of temperatures is almost imperative. As a minimum, the temperature *entering* each building load system should be sensed. As the temperature increases beyond the control range at any point, an upstream source unit is put on the line. Again consideration of relative location of loads and sources along the loop will dictate which units to cycle.

There are some elements of caution which must be exercised in developing a system of this type:

1) Since the entering chilled water temperature will exceed that normally designed for, cooling coils must be selected for the higher entering water conditions. This may necessitate, in some cases, higher flow rates per ton of cooling requirement in the building circuits.

2) Humidity-critical loads such as computer rooms, operating rooms, etc., if incorporated into the loop, must be done with caution. Experience has shown that when used for comfort cooling only, higher than design loop temperatures have been tolerated, resulting in space-humidity levels above design. The operators of the systems have found this mode of operation perfectly acceptable. This mode could not be tolerated, however, if such humidity-critical loads existed.

3) The simplified flow diagrams of Figs. 47-3 and 47-4 are presented simply as an example. However, the feature which is most significant is that, hydraulically, the primary pumping system of the loop must be completely independent from the building or source-pumping systems. To retain this independence, the supply and return connections to each building should be made immediately adjacent to one another with no changes in loop piping size. Furthermore, the loop flow rate should never drop below the extraction rate at any point.

4) In the building connection circuit, the chiller should always be circuited downstream

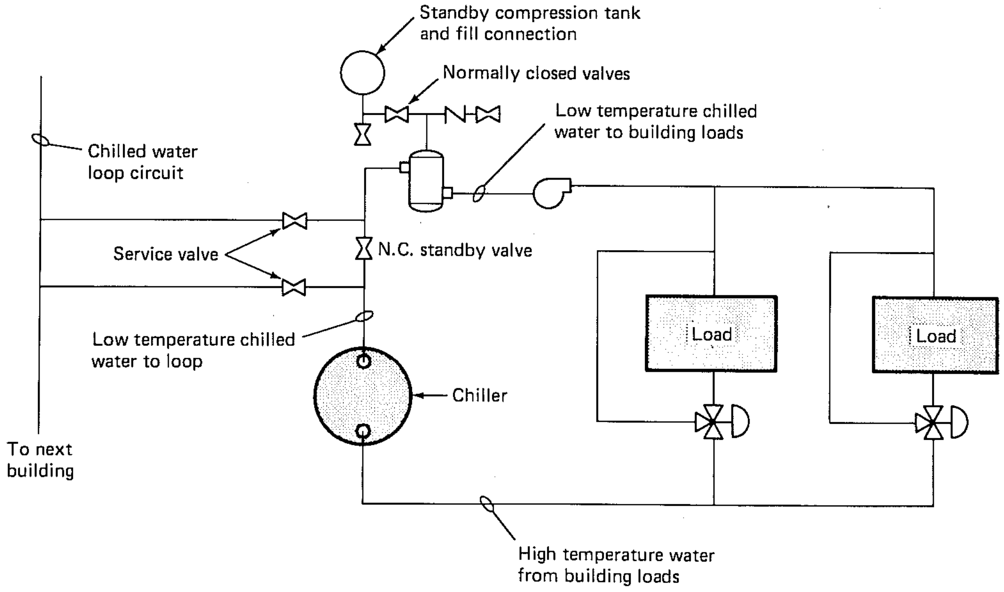

Fig. 47-8.

of the load, i.e., on the end *entering* the loop. The reason is to make available to the chiller the highest possible water temperature.

Aside from these limitations and caution, there are no further differences in the building system piping arrangements from a more conventional chilled water system design. For instance, the building system can be arranged for variable flow—primary, secondary, etc. To achieve energy economics, if sufficiently sophisticated control is provided, the primary loop flow can be reduced with load reduction.

From the standpoint of reliability, this system has the same inherent weak link of any centralized system, in that failure of the primary pumping system or a rupture in the distribution piping would affect the entire campus. Figure 47-8 indicates a method of separating the buildings from the loop under such conditions by the simple addition of a valve, and standby operation compression tank and fill connection. This feature is not attainable with central plant systems.

Summary

The integrated decentralized loop chilled water system provides many of the advantages of a central plant system with the additional advantages of:

1) standby operation in the event of loop failure;

2) lower investment cost in distribution piping.

It is applicable to:

1) existing campuses or building complexes where the decentralized approach has been taken on a "growth" or piecemeal basis;

2) new campus-type developments where scheduling of building construction and development is such that the central plant cost burden for the initial buildings is not feasible.