

# 48

## A case study of an integrated decentralized chilled water system

*Solution maximizes utilization of existing chiller capacity and upgrades overall campus air conditioning while reducing machine operating hours and operating and maintenance costs.*

The campus of the University of Missouri at Rolla, like many others, reflects the changes in building technology that have occurred over the past half century—a period in which the mechanical and environmental disciplines of that technology were changing at an exponential rate. The problem posed by such a situation is one of periodically reevaluating older buildings from a functional point of view and arriving at decisions as to whether capital should be invested to upgrade these spaces environmentally and functionally or whether they should be abandoned to obsolescence.

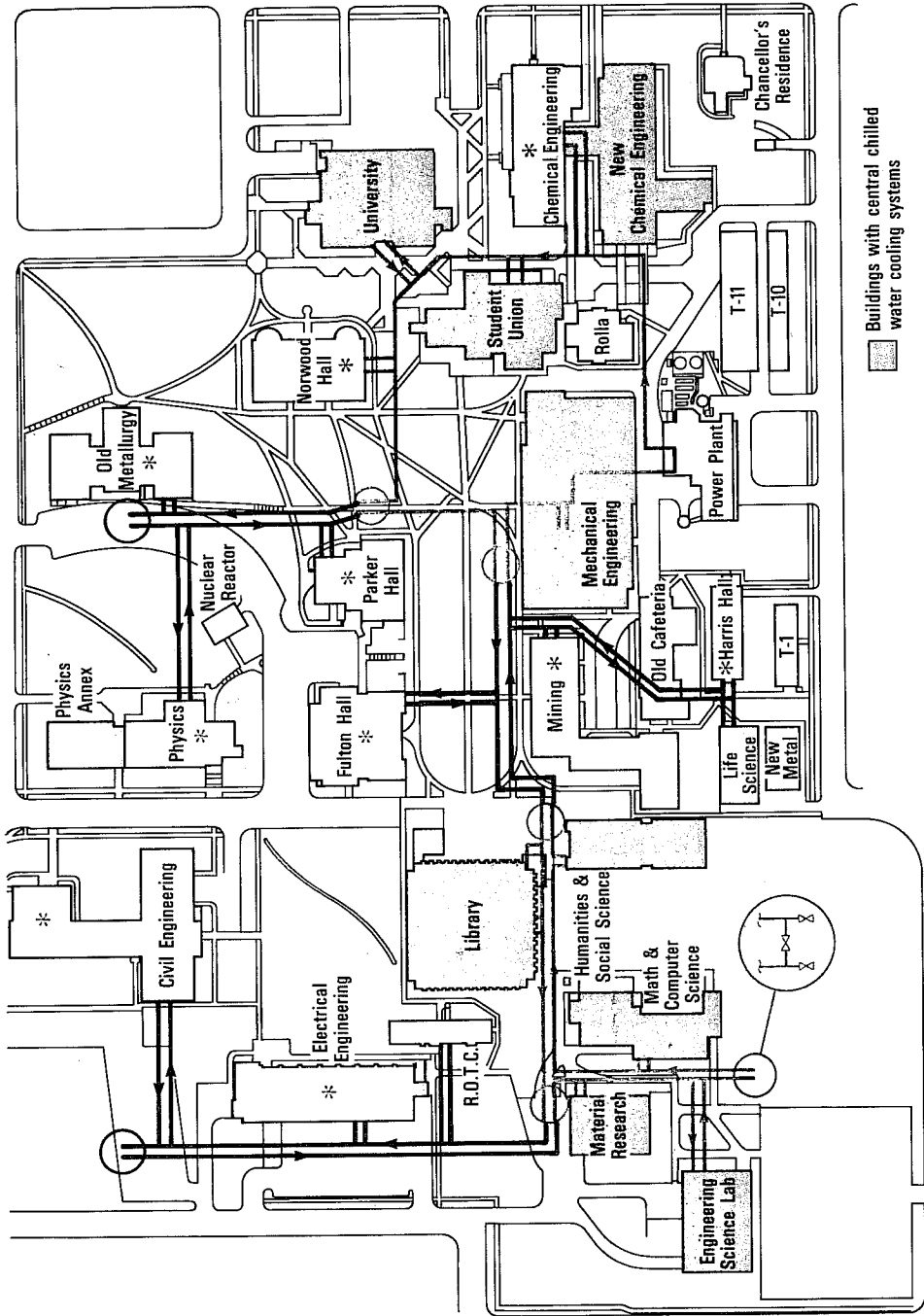
The Rolla campus at the time of this undertaking consisted of 30 buildings including the power plant, as shown in Fig. 48-1. Ten are served by modern central chilled water cooling plants; nine of these systems have absorption chillers, while the remaining one has an electric motor-driven centrifugal unit. Total installed chiller capacity is approximately 1817 tons. Steam for the absorbers is supplied from the power plant, which also provides steam for space heating and domestic hot water heating. The low-pressure steam is available as a by-product of power generation. Table 48-1 lists the buildings having central chiller systems.

Cooling in the remaining buildings is provided by unitary equipment, window units, or both. Generally, only partial cooling is provided in these structures. In service are 53 pieces of unitary equipment totaling 424 tons of capacity and 246 window units with a combined capacity of 325 tons. Tables 48-2 and 48-3 show the distribution of this equipment throughout the campus.

A study was undertaken to evaluate the present and future cooling needs of the Rolla campus and determine the feasibility of developing a single chilled water plant. The objectives were to reduce energy consumption, operating costs, and maintenance costs while increasing reliability and maximizing the useful life of the equipment.

Obviously, the existence of approximately 1817 tons of chiller capacity could not be ignored because of the capital investment involved and the long service life that this type of equipment can provide. The challenge was therefore to develop an integrated system making maximum use of the existing central plant type equipment. This led to the *decentralized* central plant concept in which the existing chillers would be tied together by chilled water loops.

An inventory of the existing chiller systems



**Fig. 48-1.** Campus of the University of Missouri at Rolla. Buildings shown by shaded areas have central chilled water refrigeration plants. Shaded piping shows Loops 1 and 2, Loop 1 at left and Loop 2 at right, in proposed construction phases to ultimately provide cooling to most of the campus from the existing chiller systems. Together with the black piping, they make up the Sigma Loop envisioned in the third phase of development. Installed capacity will handle virtually the entire campus because of diversity in building loads. Future piping connections for the initial loops and final loop are shown by the circles on the piping layout. Buildings marked with asterisks are those considered for inclusion in the Sigma Loop system.

**Table 48-1 Buildings served with central chilled water systems.**

Building	Area, sq ft	Equipment	Installed tons
Physics Annex	14,800	Absorption	71
New Chemical Engineering	78,600	Absorption	360
Library	85,600	Absorption	274
Mechanical Engineering	38,922	Absorption	200
Student Union	17,900	Centrifugal	115
University Center	38,400	Absorption	204
Materials Research	28,600	Absorption	120
Math & Computer Science	35,900	Absorption	123
Humanities & Social Science	30,600	Absorption	155
Engineering Science Lab	42,400	Absorption	195
Totals	411,722		1817

was followed by a thorough analysis of their operating characteristics. The system evaluations provided revealing information that emphasizes the need to take into account energy utilization in environmental systems design.

This chapter deals with the development of the integrated chilled water system. Chapter 23 explores energy economics concepts and shows how the work at the Rolla Campus underscores the need for considering these concepts in all building design programs.

### Existing chiller systems

Descriptions of the central cooling systems on campus are given in what follows. Flow diagrams showing major system components were prepared for all of these buildings.

- *Physics Annex*—Its system includes a 71-ton absorption chiller and a crossflow cooling tower with an indoor sump. The air side system includes a 12-ton multizone unit, heating-cooling unit ventilators on a two-pipe distribution system, and fancoils on a two-pipe system. Perimeter finned-tube radiation is provided in some spaces. Space and piping arrangements have been provided for the future addition of another absorption unit with associated pumps and cooling tower.

- *New Chemical Engineering Building*—This building, under construction at the time of the study, is served by a single 380-ton absorption unit. The air side consists of two high-velocity central station type air handling units supplying dual duct variable volume

**Table 48-2. Unitary cooling inventory.**

Building	Installed tons
Rolla Building	10.0
Physics Auditorium	25.0
Norwood Hall	15.5
Parker Hall	60.0
Fulton Hall	15.0
Harris Hall	37.5
Old Cafeteria	12.5
Old Metallurgy	2.0
Civil Engineering	35.5
Chemical Engineering	18.0
Chemical Engineering Addition	15.0
Electrical Engineering	23.0
Reactor	7.5
Life Science	17.5
T-10	5.0
T-11	20.0
T-C	17.5
Math and Computer Science	87.0
Total tonnage	423.5
Total number of units	53

T denotes temporary buildings

**Table 48-3. Window unit inventory.**

Building	Units operating	Total tons
Rolla Building	15	21.4
Physics	5	7.8
Norwood Hall	32	54.2
Parker Hall	1	0.8
Fulton Hall	30	37.2
Harris Hall	12	12.2
Old Cafeteria and T-6	2	3.2
Old Metallurgy	6	5.2
Civil Engineering	9	15.5
Chemical Engineering	41	66.0
Mechanical Engineering	2	3.2
Electrical Engineering	21	24.2
Reactor	5	4.1
Life Science	3	3.0
T-10	4	7.8
T-11	4	5.9
T-1	4	2.7
T-2	9	10.7
T-4 (Military Classroom)	4	5.0
T-7 (Military Supply)	3	2.8
Chancellor's Residence	8	7.5
Mining	26	24.4
Totals	246	324.8

terminal devices. The two central station coils are wild-flow devices and represent the only two "loads" on the chilled water system. Computer rooms, which require close control of relative humidity, are provided with self-contained air-cooled units, each of 7½ ton capacity.

- **Library**—The library is served by a single 275-ton absorption unit located in a penthouse equipment room. The air side consists of two high-velocity dual duct air handling units located in a room immediately adjacent to the chiller room. The cooling coil banks in the built-up units, running wild with an uncontrolled cold deck, are the only chilled water users. Heat dissipation is through multiple forced draft cooling towers located on the roof adjacent to the equipment room.

- **Mechanical Engineering Building**—Only the 38,920 sq ft addition to this building, built in 1967, has been provided with central air conditioning. The cooling source is a 200-ton absorption unit. On the air side are 36 ceiling-mounted four-pipe air handling units with chilled water coils supplying terminal reheat coil zones. Supplemental perimeter heating is done with wall hung convectors.

- **Student Union**—This is the building that employs the electric motor-driven centrifugal chiller. It is a 125-ton hermetic packaged unit. The distribution system is a two-pipe hot and

chilled water network serving three central station air handling units and 44 terminal fan-coil units.

- **University Center (new Student Union)**—Chilled water to cool the building is provided by a 200-ton absorption unit located in a ground floor mechanical equipment room. Condenser water is cooled by a roof-mounted cooling tower. The chilled water distribution is separate from the hot water distribution (four-pipe) and supplies three multizone air handling units and one small draw-through conditioner. The kitchen makeup air unit is not provided with a cooling coil.

- **Materials Research**—A 120-ton absorption chiller located in a ground floor equipment room supplies chilled water to a two-pipe hot-chilled water distribution system serving room terminal units, which include a combination of unit ventilators and fan-coil units. Outside air is supplied to those units toward the building interior by a nonpressurized central outside air intake duct system. The cooling tower is located on the roof.

- **Math & Computer Science**—Cooling is provided by a 170-ton absorption unit located in a penthouse equipment room. The cooling tower is roof-mounted. The terminal system is supplied by three high-pressure central station air handling units (zoned south-interior-north), which utilize terminal reheat units for

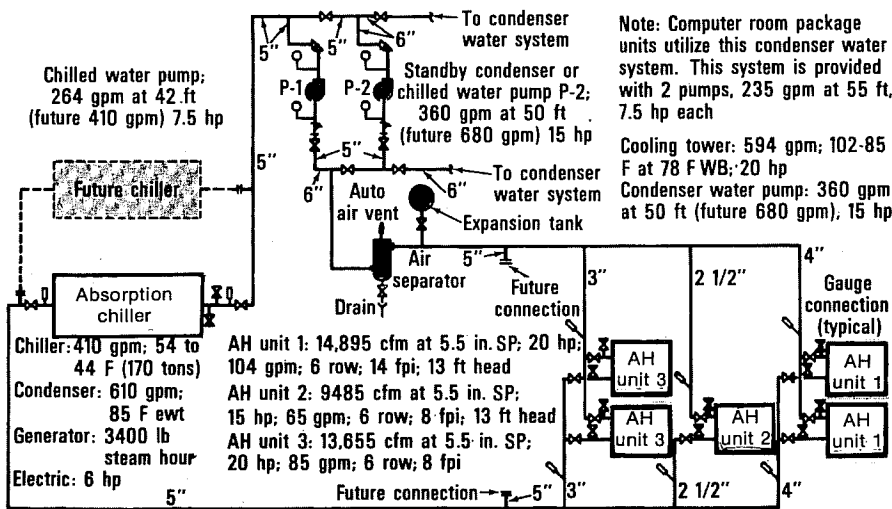


Fig. 48-2. Flow diagram is for central cooling plant in Math & Computer Science Building. It is representative of those prepared for all buildings with central plants.

space control. A computer area is served separately by five water-cooled self-contained units for year-round temperature and humidity control. Computer room units are supplied with condenser water from the same tower serving the absorption unit, but separate pumps are provided. Flow diagram and equipment data for this system are shown in Fig. 48-2.

- *Humanities & Social Science*—Building cooling is provided by a 135-ton absorption unit located in a central grade-level mechanical equipment room. A terminal reheat medium-pressure central station air handling unit is located in the same equipment space. This terminal reheat system provides conditioning for the entire first floor and interior spaces and corridors on the second and third floors. A two-pipe unit ventilator system provides conditioning for the second and third floor classrooms, and the same piping loop serves two-pipe fan-coil units in the offices on these floors. Supplementary heat by convectors and finned-tube radiation is provided where required in lobbies, entries, etc.

- *Engineering Science Laboratories*—The completely air conditioned building is provided with chilled water by a 200-ton absorption unit located in a basement mechanical equipment room. The chilled water is circulated through three central station air handling units that provide space conditioning through high-velocity terminal reheat distribution systems. The condenser cooling water is provided by a roof-mounted cooling tower. Air handling units and all other major equipment items are located on the lower level.

### Plan for long range

Discussions with the university staff and inspections of the buildings not currently provided with permanent central year-round air conditioning systems yielded helpful information with regard to long-range planning.

Buildings considered to be of sufficient continuing value to campus operation to warrant upgrading through the addition of cooling apparatus (though remotely in many cases because of building age) were included in

the initial integrated campus cooling source analysis. These buildings are so indicated by asterisks in Fig. 48-1.

The Old Metallurgy Building was dropped from the final analysis because of its age and type of structure, which definitely rendered a major investment in central cooling impractical from an economic standpoint. Connections to the loop were shown for this and some other buildings not included in the analysis because of their proximity to the proposed campus distribution routing, however. Added chiller capacity would have to be installed to handle buildings not included in the final analysis.

### Load analysis

After the installed air conditioning equipment was surveyed, building cooling loads were calculated to determine how they compared with installed capacity. A detailed computerized load calculating program, available from a time-sharing computer service, was used to generate the load figures. The results are shown in Table 48-4. The buildings that are served by machinery capable of being tied into a loop system have a combined peak load of 1403 tons against an installed capacity of 1817 tons. The arithmetic sum of the peak building loads is nearly 25 percent less than the available tonnage.

It is apparent from these figures that the chillers can handle much more space than they do now since one of the major advantages of supplying a group of buildings from either a central plant or an integrated loop system is the noncoincident nature of the various peak building loads. Load diversity would permit the chiller equipment to serve additional buildings whose individual peak loads added to the present arithmetic load sum would total more than 1817 tons.

The major advantages of the primary loop system are:

- Existing machinery is used as components of the basic system.
- The distribution system (loop) allows for unlimited addition of building loads and

**Table 48-4. Calculated cooling loads versus installed capacities.**

Building	Area, sq ft	Cooling load, tons	Installed capacity, tons	Load, sq ft per ton
Buildings with central cooling systems				
Physics Annex*	14,800	37	71	400
New Chemical Engineering	78,600	268	360	293
Library	85,600	144	274	594
Mechanical Engineering (1967 addition)	38,922	200	200	194
Student Union	17,900	122	115	147
University Center	38,400	166	204	231
Materials Research	28,600	101	120	283
Math & Computer Science	35,900	87	123	413
Humanities & Social Science	30,600	123	155	249
Engineering Science Lab	42,400	155	195	274
Totals average	411,722	1403	1817	293
Buildings with packaged and window units—				
Parker Hall	25,500	54	60.0	473
Mechanical Engineering (1949)	17,200	84	0	205
New Metals Building*	4,050	20	20.0	202
Electrical Engineering	46,200	135	23.0	342
Civil Engineering	61,900	150	10.5	412
Harris Hall	18,250	72	37.5	254
Fulton Hall	29,300	98	15.0	300
Old Chemical Engineering	46,302	141	33.0	328
Mining	25,000	97	0	258
Physics	25,400	98	25.0	260
Norwood Hall	50,900	140	15.5	364
Rolla Building*	12,620	30	0	420
Life Science*	4,704	15	17.5	314
Totals average	367,326	1134	257	330
Total load, all buildings, used in analysis		2435		
Total installed chiller capacity used in analysis			1746	

\*Not included in final system analysis. Contribution of Physics Annex chiller considered too small to warrant expense of typing it into proposed loop. Old Metallurgy Building not listed in this table because of prior decision that it would be impractical to install central cooling in it.

chiller sources with campus expansion. This *open-end* design flexibility cannot be achieved with any other concept.

- Investment in piping is minimized because mains sized to carry the summary load are not required.

- Pumping horsepowers are minimized because water flow rates sufficient to carry the summary load are not required.

### Loop analysis

In view of the above, the sizing and routing of the piping loop are important factors. The basic concept of the campus loop system is to connect the loads and the refrigeration sources in series in such a way as to allow the loop temperature to rise as it satisfies the loads of several buildings. Then the temperature is again reduced by another chiller to provide for

the cooling needs between that connection and the next cooling source.

To best take advantage of this concept, a thorough analysis of the loads on each building and their characteristics of coincidence with other building loads at each hour of the year is needed. The *design* condition, the time of year that the loop *sees* the maximum load, is then determined.

After the maximum diversified load was determined, a trial and error method was employed to select the loop routing that would result in the minimum decrement of the cooling capability of the loop. The analysis was then performed at the various reduced-load conditions to determine which combination of load/source locations would result in the minimum number of chillers to satisfy the maximum number of loads.

Computer programs for developing energy

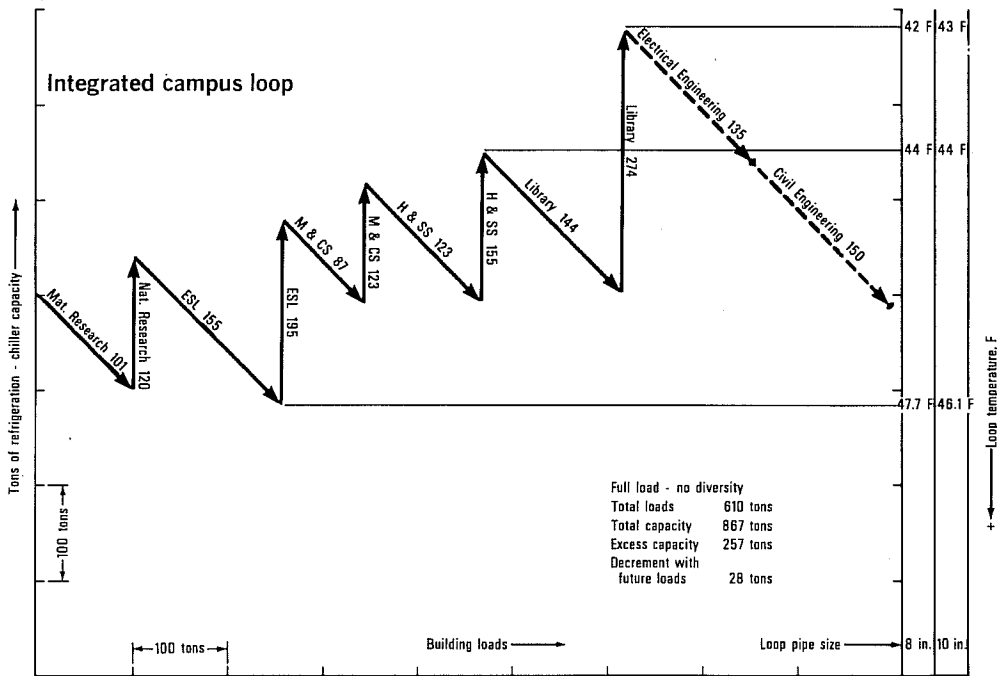
consumption and part load performance data were used to determine the various load data and annual hours of refrigeration required for the different loops. It was necessary to modify these programs to obtain the desired information. The programs were run for each building, and the results were then run against one another for the alternate combinations of loop configurations.

**Loop split into three phases**

The development of the loop was split into three phases for construction budgeting purposes. The first two call for the interconnection of adjacent buildings into two separate loops and placing the chillers into loop operation. The third phase calls for the connection of the two loops and extending the loop to pick up buildings proposed to be served by the existing chillers. The loops in the first two phases are denoted as 1 and 2, and Sigma Loop is the ultimate design (see Fig. 48-1).

The results of the loop performance studies are shown in Figs.48-3, 48-4, and 48-5, which are actually warped bar charts. The vertical axes represent tons of refrigeration capacity; on the right-hand side are temperature ranges encountered in 8 and 10 in. diameter pipe loops. The horizontal axes represent building cooling loads in tons. The charts represent full load building quantities because system diversity applies to the loop as a whole and not to individual buildings.

Temperature of water entering a building from the primary loop is taken at the tail of the appropriate diagonal arrow. Temperature in the loop after the water has returned from a building that does not have a chiller is taken at the head of the diagonal arrow. Temperature in the loop after the water has returned from a building that does have a chiller is found opposite the head of the vertical arrow. Cooling of such a building is accomplished with water from the primary loop before it enters



**Fig. 48-3.** Temperature-capacity gradient diagram for Loop 1 shows performance of Loop 1 (at lower left of Fig. 1). Starting at left chilled water from the loop enters Materials Research Building, absorbs building load of 101 tons (angled line), then gives up 120 tons of heat to the building chiller (vertical line), and re-enters the loop at a lower temperature than when it entered the building. Cycle is repeated throughout the remaining buildings in the loop. Ranges of loop temperatures for 8 and 10 in. piping are shown at right. Dotted lines show effect on loop temperatures if the Electrical and Civil Engineering Buildings were added to the loop and cooled by the excess chiller capacity in the other buildings.

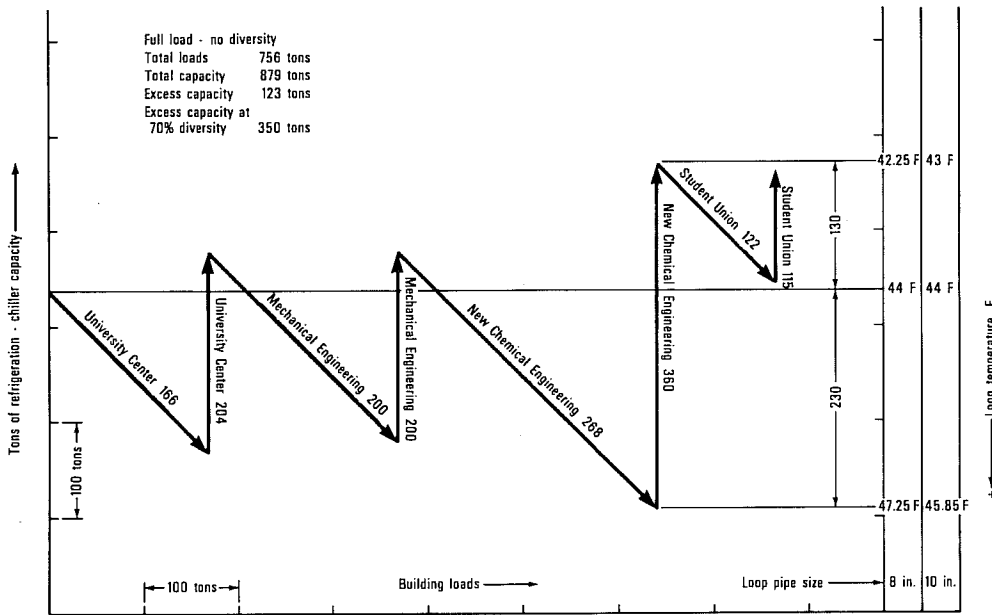


Fig. 48-4. Temperature-capacity gradient diagram for Loop 2 shows performance of Loop 2 (lower right in Fig. 1). Again, angled lines represent building cooling loads, and vertical lines represent installed building capacity.

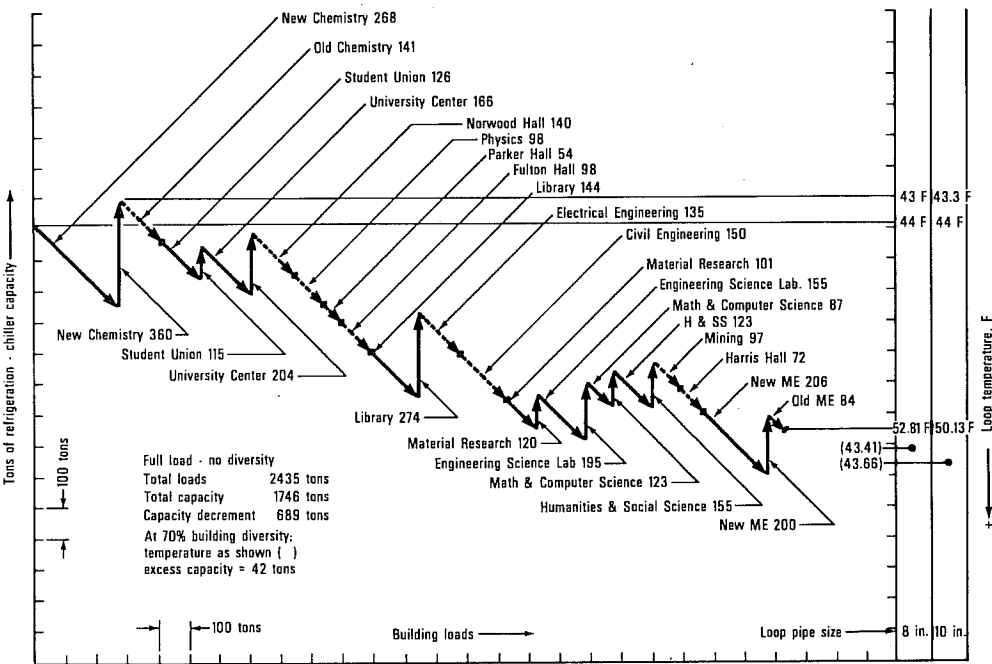


Fig. 48-5. Temperature-capacity gradient diagram for Sigma Loop—combined Loops 1 and 2 plus other connections (Fig. 1). Angled lines are building cooling loads, and vertical lines represent installed chiller capacities in buildings that presently have central plants. Temperature rises in 8 and 10 in. loops are shown at right. Closed loop temperatures with system diversity accounted for are shown in parentheses. Dotted lines show buildings that would be cooled from chillers in other buildings. Not all buildings that have connections to the loop in Fig. 1 are included in the above analysis since the age of some renders economic feasibility of adding central cooling marginal or impractical.

the chiller so that the water entering the chiller is at a sufficiently high temperature to gain maximum capacity from the chiller.

### Loops have excess capacity

Examination of Fig. 48-3 reveals that even without allowing for diversity, there is an excess of capacity in Loop 1 since the temperature of water leaving the chiller in the library is lower than the temperature of the water entering the Materials Research Building. Adding the Electrical and Civil Engineering Buildings to the loop utilizes the excess capacity, assuming all individual peak loads are additive. With the 70 percent diversity factor calculated for this loop, however, there is an excess capacity of 240 tons.

Figure 48-4 reveals that at full load, without allowing for diversity, there is an excess capacity of 123 tons in Loop 2. Allowing for diversity, the excess is 350 tons.

Sigma Loop is shown in Fig. 48-5. The 70 percent system diversity changes the capacity decrement of 689 tons when all peak loads are added arithmetically to a surplus chiller capacity of 42 tons. It should be noted that on a diversified basis the temperature leaving the Old Mechanical Engineering Building will be approximately equal to that entering the New Chemical Engineering Building.

Examination of Sigma Loop routing and loading in Fig. 48-1 and Fig. 48-5, respectively, shows that the selected routing provides for the higher loop temperatures at buildings not having central chilled water systems. In these buildings, designers need only select cooling coils and other apparatus on the bases of the available water temperature at the point of connection and the allowable temperature range in the building loop. While these are not difficult restrictions, it is important that they be met if the integrated primary loop concept is to be successful.

It should be stressed that the limiting factor is the maximum temperature at which chilled water can be supplied to a building load from the loop and still provide adequate dehumidification and sensible cooling in the building. Of the two, the latent or humidity control parameter is the more readily affected. The

survey of the facilities revealed that those areas on campus requiring close humidity control are provided with independent environmental control systems whose inclusion in the integrated campus system is not contemplated. Thus, the acceptable temperature rise of the loop is directly dependent on the tolerable ranges of relative humidity for normal occupant comfort. Based on the ASHRAE comfort standards, loop interconnection design should be based on a 44 F inlet to the coil with a 16 F range to achieve 75 F DB and 50 percent RH. With entering water temperature and coil dew point swings up to 49 and 60 F, respectively, it was possible to maintain 75 F DB with a maximum rise in RH to 60 percent. Any future critical humidification applications should *not* be connected to the integrated system. All loads that represent comfort cooling *should* be connected.

Temperatures of water entering buildings having chillers are kept as low as possible to minimize changes in existing apparatus. In some instances, additional rows of coils were required. In other cases, there is currently excess coil capacity that can be utilized.

### Loop pipe sizing

As stated above, one of the advantages of a loop-type campus system is that the series-connected load and source concept results in minimum pipe sizes for an infinite growth of summary load. Two major considerations in pipe sizing are:

- What is the largest single load or source that will be connected without an accompanying source or load, as the case may be?
- What is the anticipated full load and part load temperature decrement that can be tolerated?

In the study, four basic sizes were considered, 6, 8, 10, and 12 in. The assumed maximum flows of these four sizes are 800, 1700, 3000, and 5000 gpm, respectively. Preliminary analysis led to the rejection of the 6 and 12 in. loops, leaving the 8 and 10 in. loops for further consideration.

The tonnage represented by a load or source

connection to the primary loop is calculated by dividing the product of flow rate (in gpm), 500, and temperature range by 12,000. A maximum temperature range of 16 F in the secondary circuits leads to the following limitations for a *single* load or chilled water source:

- 8 in. primary, 1700 gpm: 1133 tons.
- 10 in. primary, 3000 gpm: 2000 tons.

The flow rates represent the maximum amounts of water that can be economically circulated.

In applying these limitations to the system, there is yet an additional restriction: The chiller source (if the limit is reached) must be applied at a point of maximum temperature; otherwise it cannot be applied at full capacity (16 F). The same limitation applies to a load, calculated as above, except that it must be imposed at a point of minimum loop temperature (43 or 44 F). Thus, in such cases the maximum tonnages above would have to be reduced by a factor depending on the physical location of the connection to the loop.

Figure 48-6 is a diagrammatic illustration of the method of interconnecting a building system with the primary loop. Although differences in the existing chilled water systems

will necessarily dictate some custom modifications of this scheme in the various buildings, the proposed connection method can be closely approached in all of the existing systems.

Any future buildings that are planned should include the general piping arrangement proposed, complete with valving and blind openings for the eventual loop connection.

As the final engineering design is developed for each or any incremental phase of system development, some changes to the proposed ideal connection scheme could be dictated by the loop configuration. The basic concept is the relative arrangement of the chiller, load, and loop connection to achieve minimum water temperature to the load and maximum water temperature to the chiller.

**Cooling at minimum cost**

Summarizing, the previously stated objectives of integrating the presently isolated building cooling systems into a single system are as follows:

- to optimize utilization of machinery;
- to minimize machine operating hours;
- to optimize energy utilization;
- to enhance reliability.

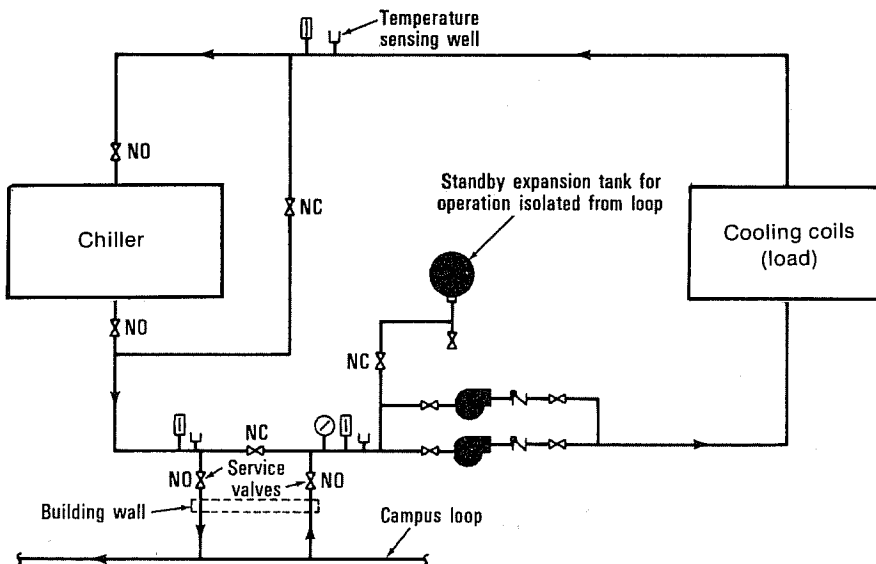


Fig. 48-6. Schematic diagram of proposed building connection to primary loop.

Inherent in the above is accomplishing campus cooling at minimum cost. In this context, cost or economic values are to be applied to virtually all measurable quantities to achieve a common denominator. The quantities involved are:

- useful machinery life;
- machinery replacement cost;
- maintenance costs (planned and unanticipated);
- energy consumption and cost;
- water;
- expendable materials (water chemicals, lubricants, etc.).

To apply a quantitative evaluation to the Rolla campus, the three basic loop developments established were evaluated, each in two different ways: first, with each building system functioning independently of the others—assuming that a central cooling plant would be added to buildings currently not fully air conditioned; and second, with the existing cooling systems integrated into the loop in the three phases of development. This was accomplished by hourly load comparisons incorporated with the reduced or part load characteristics of each chiller system. The following discussions address the energy and operating cost savings achieved.

### Energy requirements and savings

Energy consumption was considered in terms of thermal energy expressed in pounds of

steam per hour and electrical energy expressed in kilowatt hours. The part- or reduced-load steam consumptions for the absorption units were taken from the manufacturers' cataloged performance curves. Although experience in operating the units indicates that these consumption rates are seldom realized in the installed machines, there was no documentation of this and manufacturers' data were therefore employed.

The comparison was then made for the isolated unit operation and the integrated loop system in the three phases of development, and the results are given in Table 48-5. As can be seen, the annual energy cost saving that can be attributed to total campus interconnection on the Sigma Loop is approximately \$10,000.

### Machine operation hours and costs

As stated earlier, one of the major advantages of the integrated loop vis-a-vis individual systems is the capability of operating only some of the units under conditions of reduced loading. The value of machine operating hours is less readily identified than that of energy consumption and varies as a function of plant operating and maintenance techniques. The monetary value of machine operating hours is composed of the following values:

- *Capital cost of machinery*—All but one small unit in the proposed system are lithium bromide type absorption units. The basic motivating energy in these units is high-level

**Table 48-5. Amounts and costs of electricity and steam for both isolated unit and integrated loop operation in the three phases of development planned.**

Condition	Electricity		Steam	
	Quantity, KWHR	Cost, \$	Quantity, Mlb per hr	Cost, \$
Loop 1 isolated	530,668	9,021	18,821	30,114
Loop 1 interconnected	404,507	6,877	16,291	26,065
Savings	126,161	2,144	2,530	4,049
Loop 2 isolated	524,435	8,915	11,817	18,907
Loop 2 interconnected	339,504	5,772	10,650	17,040
Savings	184,931	3,143	1,167	1,867
Sigma isolated	1,499,343	25,489	45,236	72,378
Sigma Loop	1,055,831	17,949	43,800	70,080
Savings	443,512	7,540	1,436	2,298

thermal energy, which achieves the refrigeration effect through the evaporation of water at extremely low absolute pressures, motivated by a chemical process of brine adsorption. Thus, the "wear and tear" on such a unit is chemical rather than mechanical. It is reasonable to estimate the life expectancy of this type of unit at 20 years, based on 3000 hr of operation per year. Thus, the machine can be estimated to have a useful operating life of 60,000 hr. For simplification, the value of operating hours was developed neglecting value of monies, interest on sinking funds, etc., and the comparisons were made strictly on a cash value basis. Assuming an investment and replacement cost of \$250 per ton, average machine size of 181.7 tons, and the 60,000 hr life expectancy, the depreciated value of 1 operating hr of a unit was set at \$0.76.

- *Maintenance and operation cost*—Current experience on the campus indicates that the labor and materials costs for the existing units are approximately \$28,000 and \$12,000 per year, respectively. Calculations indicated that the present operation results in approximately 26,417 machine hr per year; thus, the maintenance and operation value was set at \$1.51 per machine hr.

- *Water and water chemical cost*—Although the use of water for condensing purposes is theoretically related to ton-hours rather than operating hours, research indicates that very few data have been compiled relating water consumption to reduced-load demands. It is reasonable to assume, however, that there is a drift loss and controlled bleed loss that exists in a cooling tower system regardless of the load on the system, even assuming a constant temperature-load relationship. This combined loss thus represents a parasitic burden to system operation. In the context of the study, however, the quantitative value of this parasitic loss was not determined, and no value was assigned to this consideration.

Adding the capital cost value component to the maintenance and operating cost value component results in a machine value rate of \$2.27 per hr. This rate was applied to the

**Table 48-6. Hours and value of machine operation for both isolated machine and integrated loop operation in the three phases of development planned.**

Condition	Hours per yr	Value, \$
Loop 1 isolated	12,278	27,871
Loop 1 interconnected	5,500	12,485
Savings	6,778	15,386
Loop 2 isolated	11,809	26,806
Loop 2 interconnected	3,700	8,399
Savings	8,109	18,407
Sigma isolated	62,264	141,339
Sigma Loop	13,176	29,909
Savings	49,088	111,430

calculated operating hour schedule shown in Table 48-6 for the three suggested stages of development. The overwhelming significance of the integrated loop approach becomes evident at a glance when the value of the machine hour saving for the ultimate or Sigma Loop is seen to be \$111,430 per year. Another interesting correlation is that the machine hours and associated value for the Sigma Loop are *appreciably less* than for the existing nonconnected machinery (by approximately one-half), which indicates that the existing machinery essentially comprising the Sigma Loop apparatus would operate for fewer hours to handle the entire campus than they do now, handling only ten buildings.

#### Consider sources of inaccuracy

The value of the savings developed above are not without some degree of inaccuracy. The unit value developed is felt to be as accurate as could be generated with the data known, and it can readily be adjusted if desired with further refinement of cost history. The machine operating hours data were developed by calculating the loads for each included building, evaluating the energy and part load profile for each building, and then calculating machine hours. To calculate loop machine hours, all buildings on the loop were summarized as though they responded as a single variable load; then the part load and machine hours were determined. This method of com-

putation resulted in two-sources of inaccuracy:

- Because of the loop capacity decrement, under conditions of extremely low loading, during which the program anticipated only one machine, the temperature rise limitation could be exceeded, necessitating the operation of an additional machine.
- The computerized calculations did not take into account operating tolerances beyond the mathematically ideal condition.

The coupling of these two potential inaccuracies could result in a significant difference between the foregoing predictions and operating experience. If system performance is adequately monitored, however, the deviation should not exceed a 100 percent increase in actual loop machine hours over the number predicted. This correction, applied to the Sigma Loop, would decrease the value of the savings to \$81,520—still a very significant amount.

It should also be considered that just as construction costs can be expected to increase in coming years, energy and operating costs will likewise escalate. An analysis of current market trends indicates that both of these costs will increase at a more rapid pace than construction costs during the coming decade because maintenance personnel costs are presently lagging behind construction personnel costs and the current energy shortage will undoubtedly result in significant cost increases in the near future.

### Monitoring system

To assist in gaining optimum value from the integrated loop and to retain manageable proportions over the extensive machinery that will ultimately be gathered on campus, installation of a monitoring system was recommended, beginning with the first phase of loop development.

Minimally, direct transmission to a central panel should provide temperature indication at the entrance to each load and each chilled water source; loop pump operation; loop flow indication; and loop pressure indication. Each building could be provided with a failure or "out of tolerance" indicating panel, with a single signal for each building being transmitted to the central console.

Experience has shown that future construction planning for campuses of this nature is at best a fluid situation. Any provisions in a central or integrated energy system that impose a restriction on planning or system revisions can prove economically disastrous. The future growth potential was therefore studied thoroughly, and the results yielded another plus for the integrated loop concept; i.e., since both chilled water sources and loads can be added to the system and their effects controlled completely by the individual building system design engineer, the loop system developed will be completely compatible with any future growth. The only primary loop restriction would be if any such future load or chilled water source, when translated from Btuh to gpm, exceeded the total flow capacity of the loop at the connection point.