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# SURVEY ON THE DESIGN OF RADIANT SYSTEMS FOR COMMERCIAL BUILDINGS IN CANADA

CanmetENERGY

*Leadership in ecoInnovation*

Canada

## Acknowledgment

I would like to thank my colleagues Sébastien Brideau and Kamel Hadad, researchers at CanmetENERGY Ottawa and José Candanedo, researcher at CanmetENERGY Varennes for their valuable comments and suggestions during the writing of this report. Also, I am thankful to Katherine d'Avignon, professor at l'École de Technologie Supérieure in Montreal for her collaboration during the writing of the questions for the survey.

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## INTRODUCTION

The design of radiant systems in commercial buildings is a preferred option not only for energy efficiency but also for comfort reasons, particularly for buildings designed for net zero energy consumption [Solution Sets for Net Zero Energy Buildings Ernst &Sohn 2017]. However, the design of those systems raise many questions such as do we take advantage or not of the thermal mass, the selection of the ventilation system, the control strategy associated with the different seasons,etc. CanmetENERGY who is currently doing a research project on radiant systems installed in schools was interested in measuring the level of knowledge and misunderstanding that consulting firms may have during the design of those systems. Inspired by the report ''Results from Expert Interviews'' published by TRC Energy Services and U.C.Berkeley, Center for Built Environment, the survey results reveal the consensus established during the design of radiant systems but also the significant differences related to the designers choices. The interview results from TRC/CBE are also compared with the survey results. By characterizing the gaps between the responses provided by the consultants and existing grey zones that remains a source of concern, CanmetENERGY has another tool to orient research avenues in the right direction and to develop guidelines for the design of those systems in Canada**.**

## ADMINISTRATION

Invitation to engineering consulting firms

In 2018, an invitation to respond to a survey was sent to 46 engineering consulting firms with business offices in Quebec and Ontario. The only criterion used for the preselection of firms was that they have expertise in the field of heating, ventilation and air conditioning (HVAC). The full text of the invitation reads as follows:

*I am a research engineer at CanmetENERRGY Ottawa, Natural Resources Canada. The purpose of this e-mail is to invite you or one of your mechanical engineers to complete a short survey on the design of radiant heating systems in commercial and institutional buildings. The results of this survey will assist in developing guidelines for these systems that can improve indoor comfort while reducing energy*

*consumption. We welcome those who design both radiant heating systems only as well as radiant heating and cooling systems combined to provide feedback.*

*The link to the survey can be found hereafter. I would like to thank you in advance for your participation. If you have any question on this research project, please contact me by e-mail or phone.*


Radiant heating system for commercial & institutional buildings in Canada.

English

Participation is voluntary, there are no required questions, and all information provided is protected pursuant to the Privacy Act. Several questions in this survey stem from the "Thermally Activated Building System (TABS) Radiant Cooling Design and Control in North America: Results from Expert Interviews" prepared by TRC Energy Services and UC Berkeley Center for the Built Environment, June 2017. The report is publicly available. For more information about the survey or access to alternative formats, please email michel.tardif@canada.ca.

Please complete this survey by May 31, 2018.

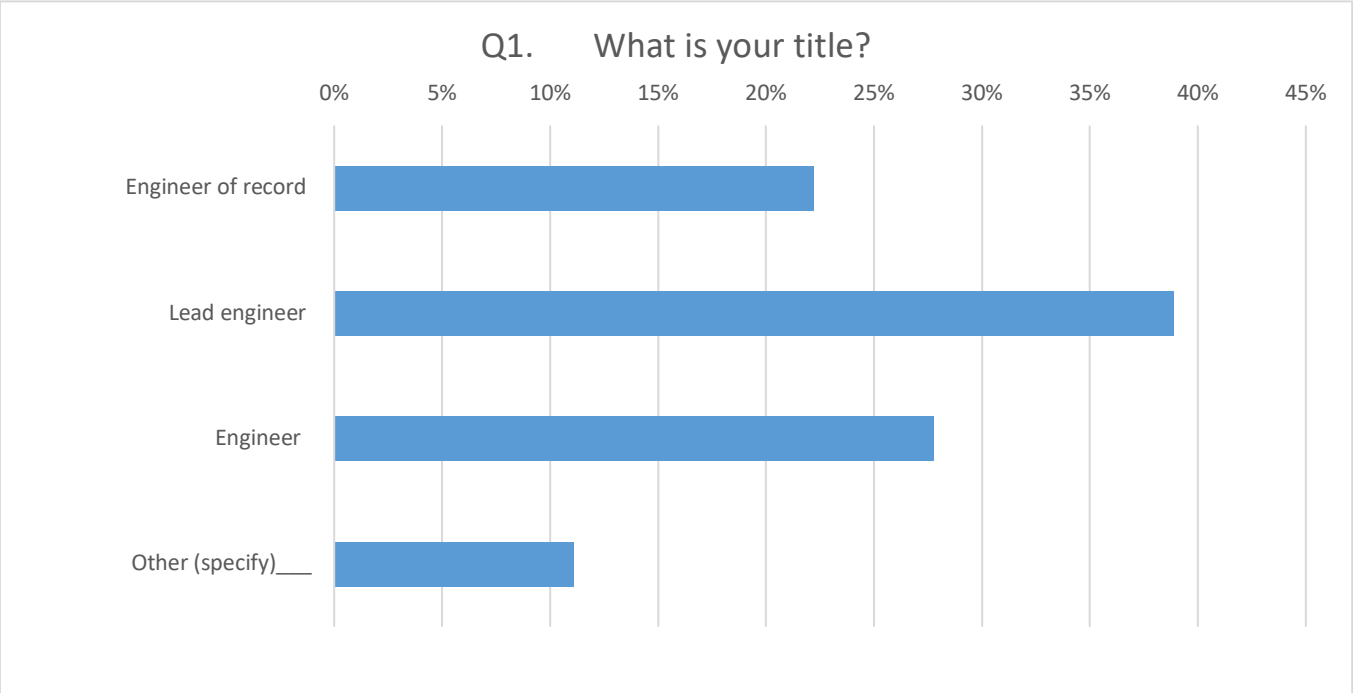
Next

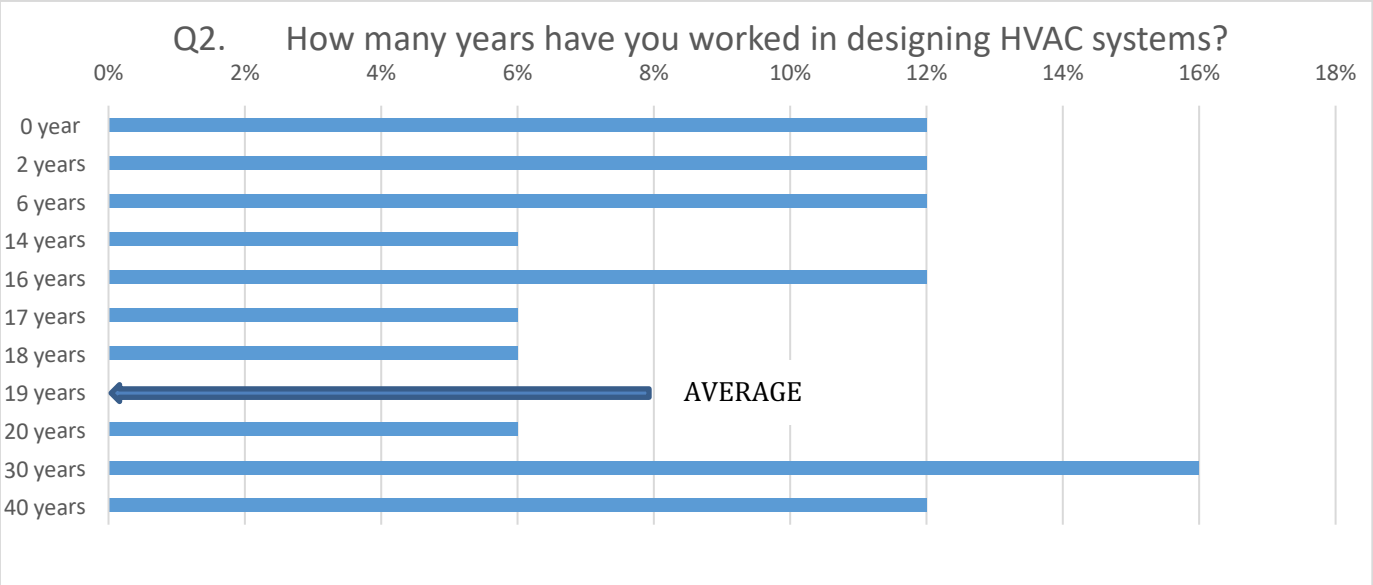
The number of firms that accessed the survey was approximately 40% (18 respondents). The response rate varied depending on the type of question. A total of 28 questions were asked, including one question about the respondent's contact information (optional) and one that asked for comments about the survey.

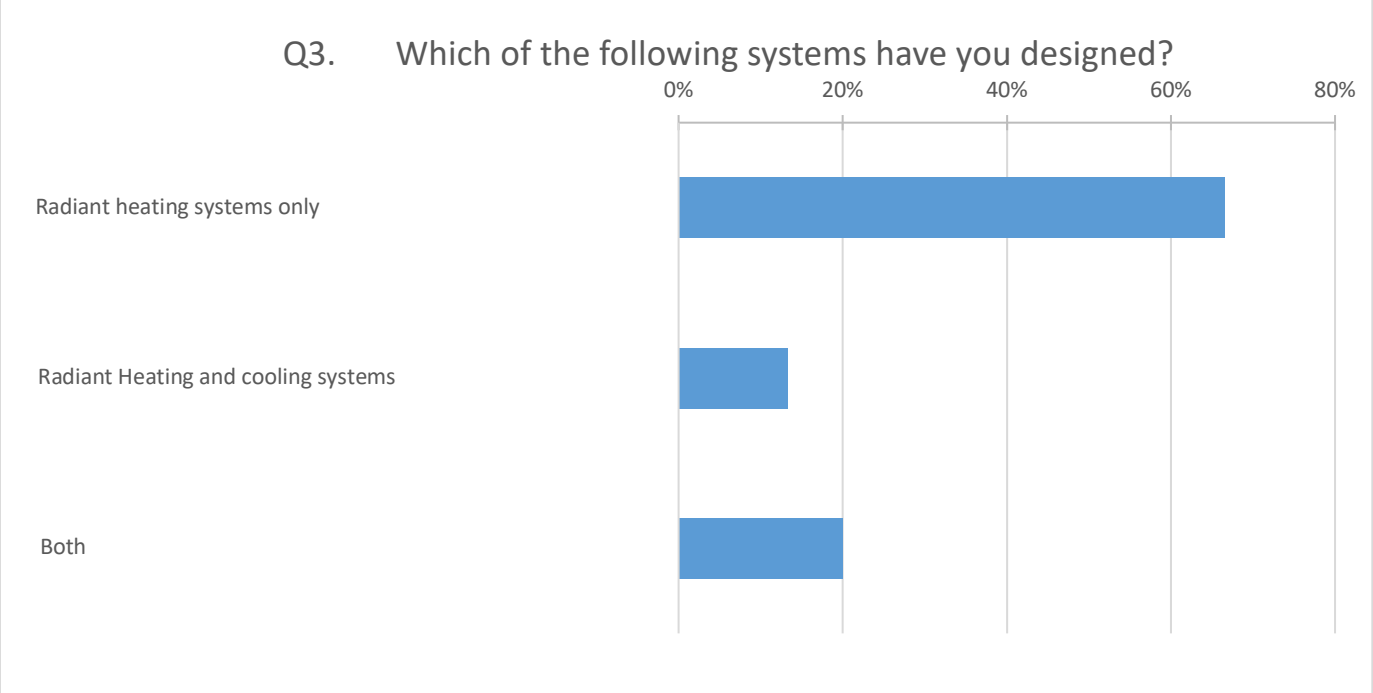
**RESULTS**

*Notice to the reader: Respondents were allowed to chose more than one response to the same question so that the overall percentage for all responses to the same question can exceed 100%*

Questions 1 to 5 related to the experience of the experts who were consulted, and in general, all were qualified as engineers (except one) with an average of over 19 years of experience, and more than half of the experts had between 14 and 30 of experience.



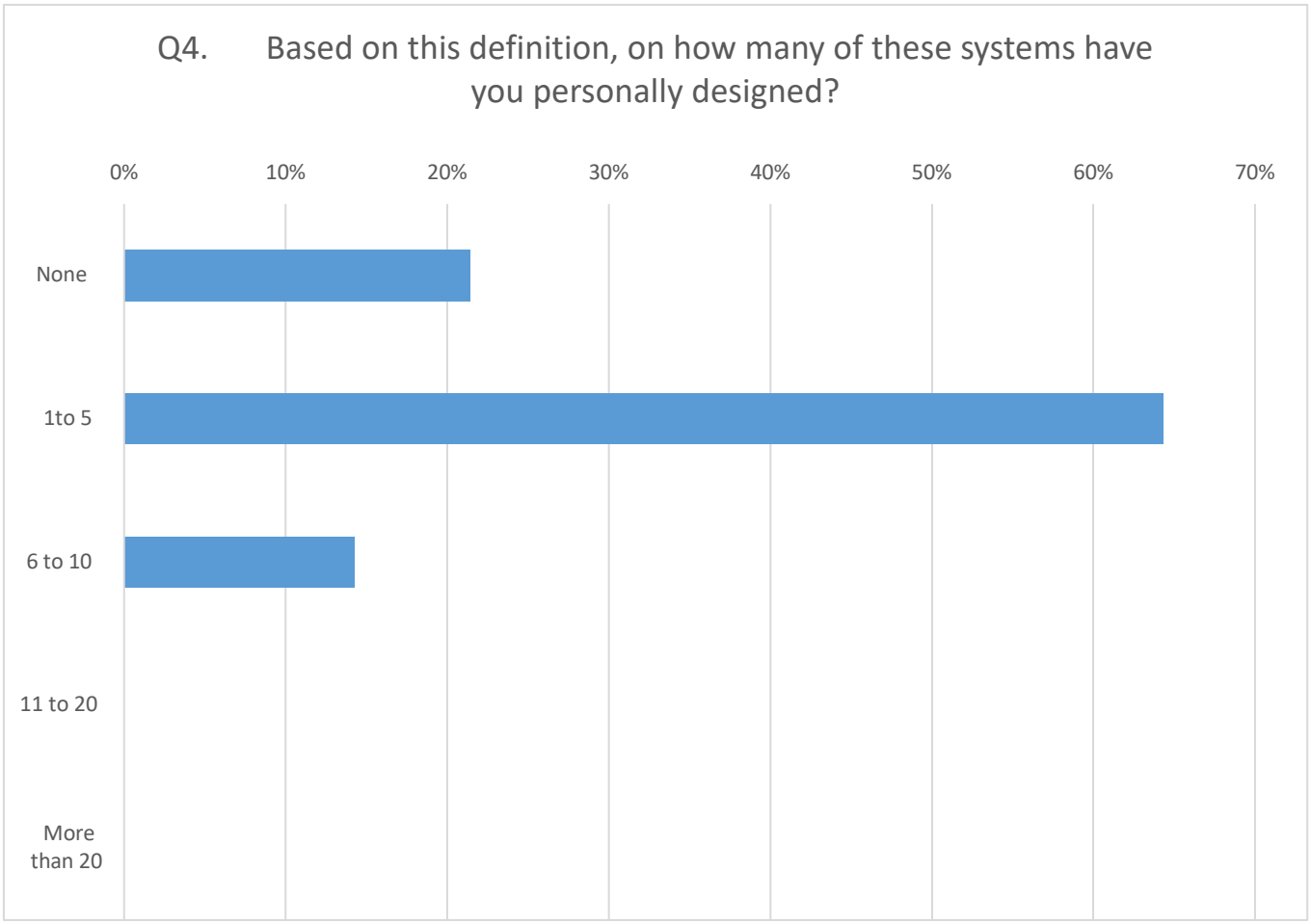

Q2. How many years have you worked in designing HVAC systems?
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
0 year
2 years
6 years
14 years
16 years
17 years
18 years
19 years
20 years
30 years
40 years
AVERAGE


Q3. Which of the following systems have you designed?
0%
20%
40%
60%
80%
Radiant heating systems only
Radiant Heating and cooling systems
Both

The majority, or 67%, of experts consulted had designed radiant heating systems only, which in Canada is more common given the predominantly cold climate. The design of TABS systems (see definition in question 4) was predominant at more than 64% compared to ESS systems (see definition in question 5) at 21%; although oddly, the number of systems such as these that had been designed was relatively low for both TABS and ESS systems. In fact, less than 14% of experts had designed more than six TABS systems, whereas only 7% had designed more than 11 ESS systems. This statistic would indicate that radiant flooring systems are still infrequently designed by mechanical engineers

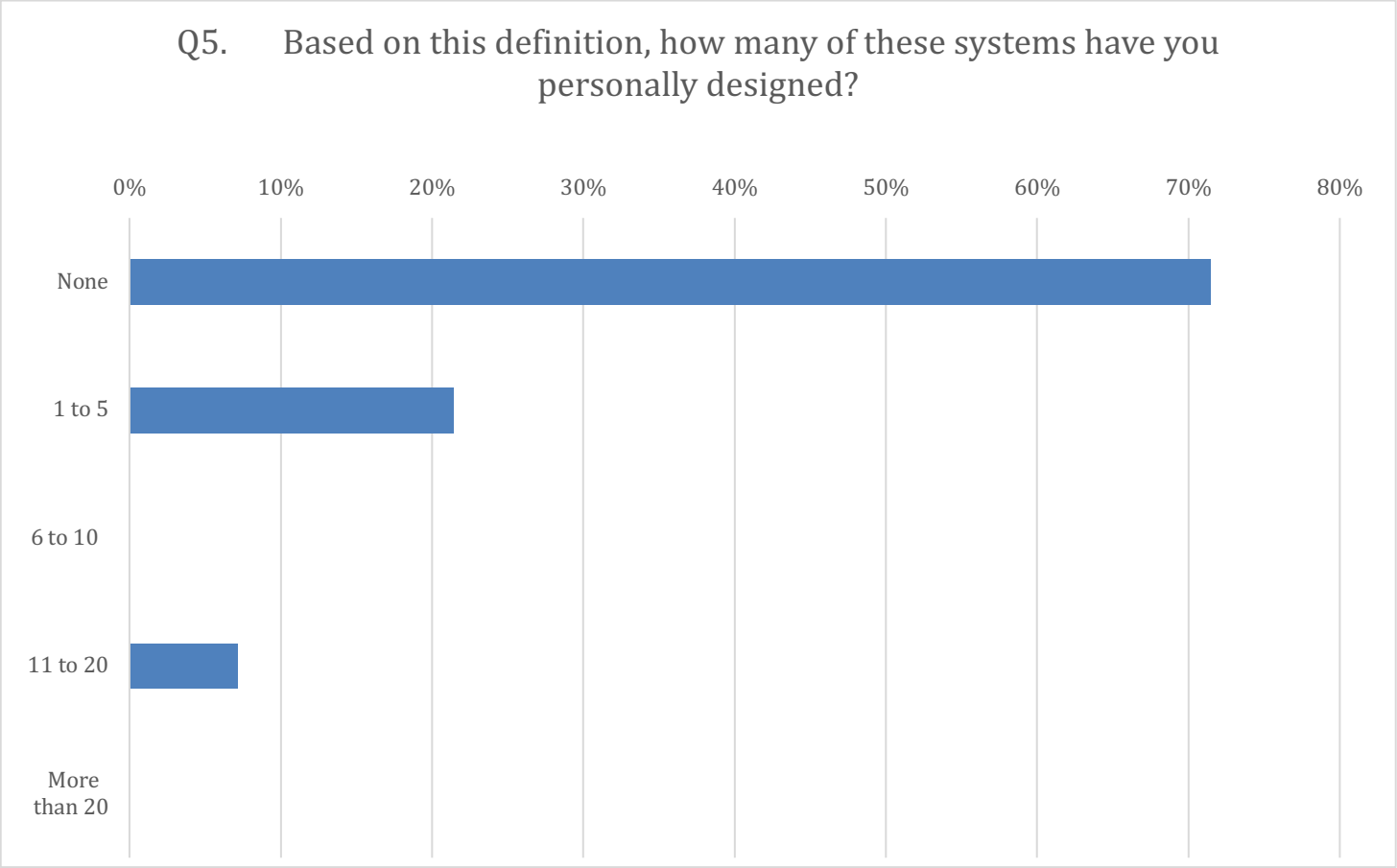
Q4. Definition

A thermally activated building system (TABS) has radiant tubing embedded in a structural slab, or in a topping slab on top of a structural slab without insulation to separate the two slabs.

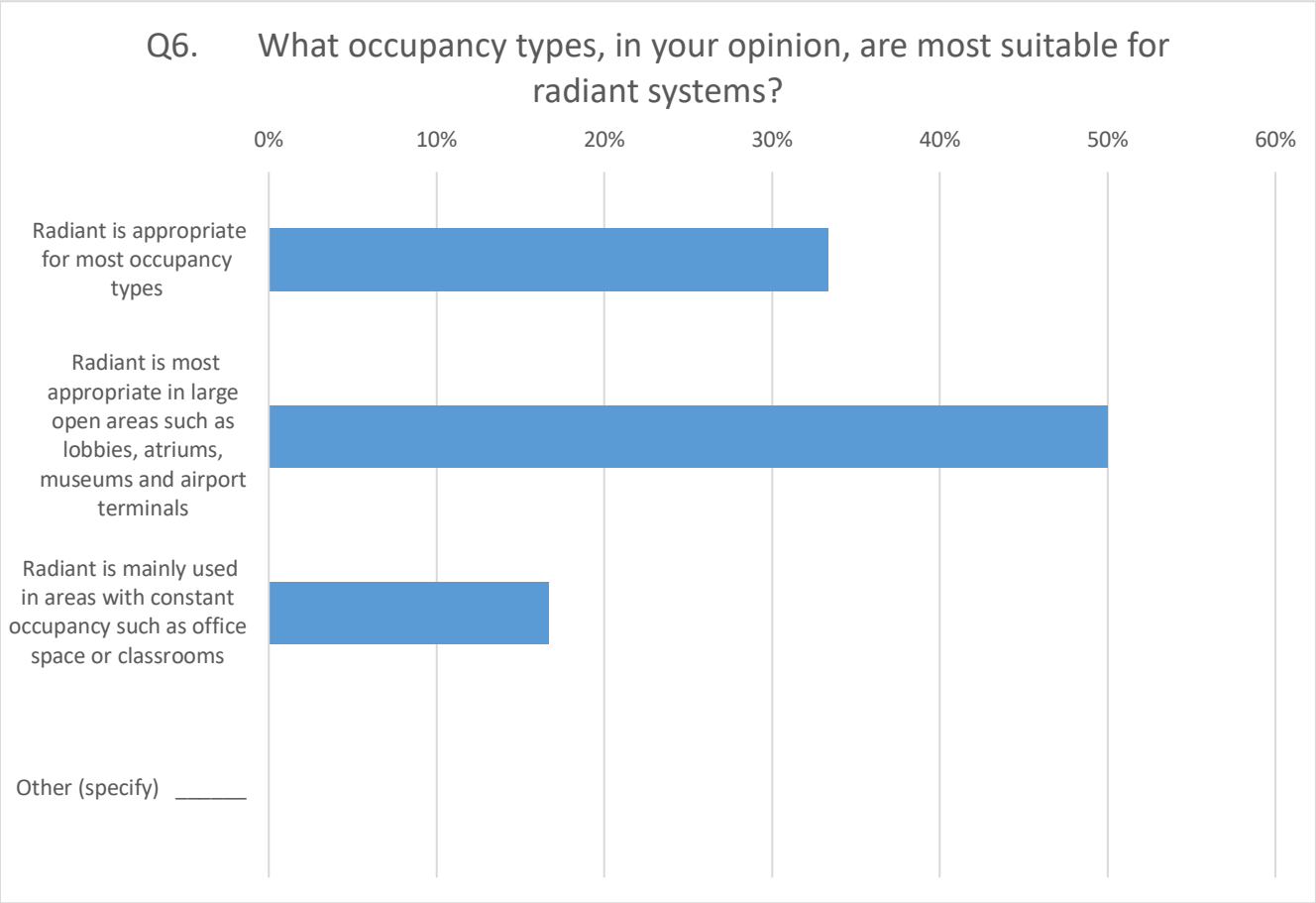


Q5. Definition

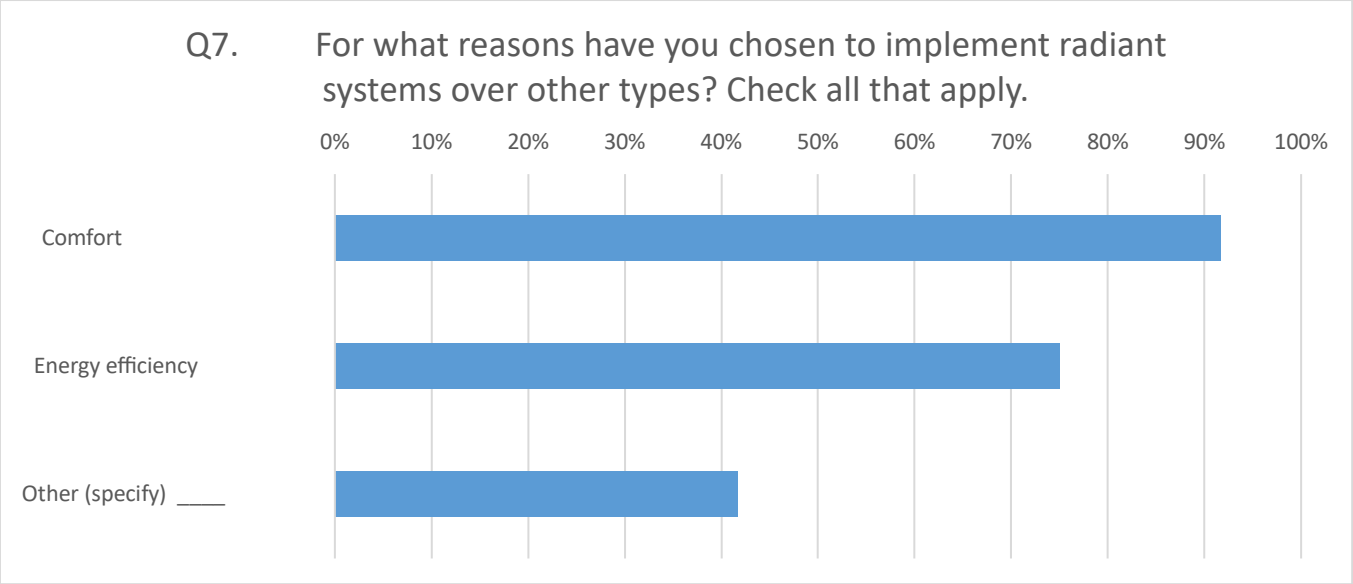
An embedded surface system (ESS) has radiant tubing embedded in a topping slab separated from the structural slab by insulation. If significant thermal mass is not activated in the design, the radiant floor system is considered an ESS.



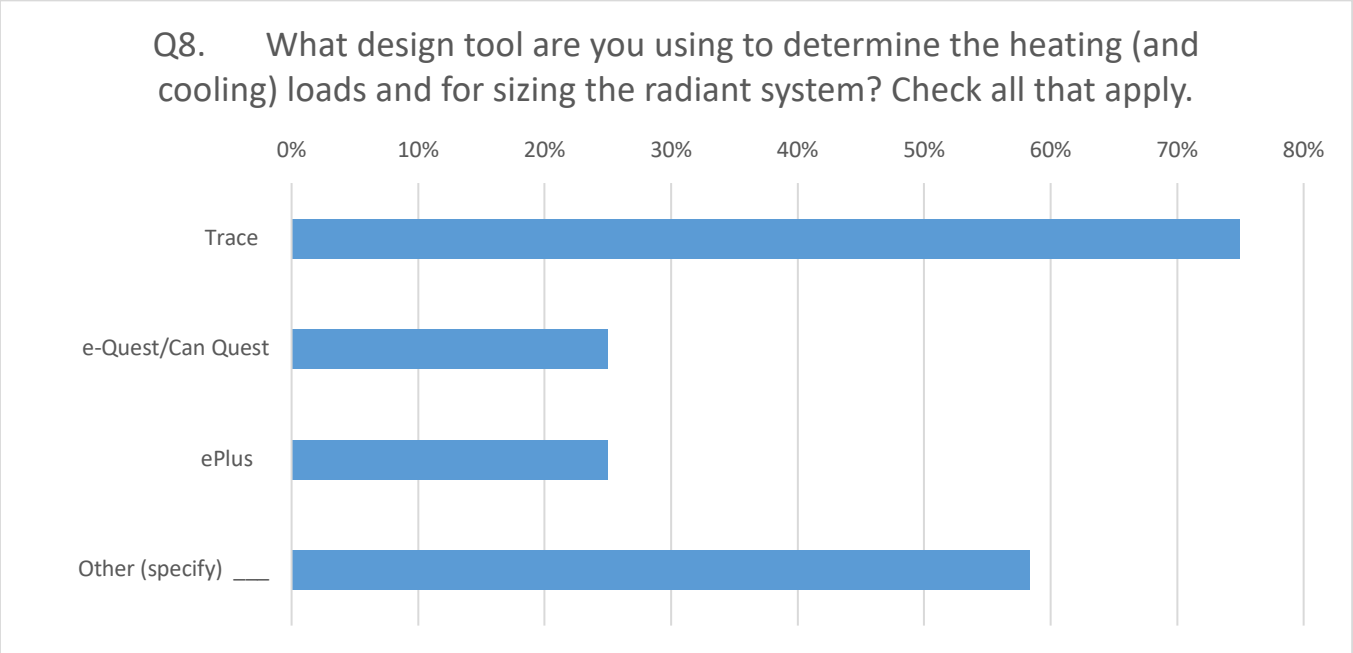
Question 6 shows that there was no consensus among the experts who were consulted. This question, which was about the most appropriate type of space, indicates that 50% identified large open spaces as more appropriate, while the other 50% was divided between those who saw these systems as suitable in any type of space (33%) and those who specified that continuous occupancy of the premises is desirable for this type of system (17%).



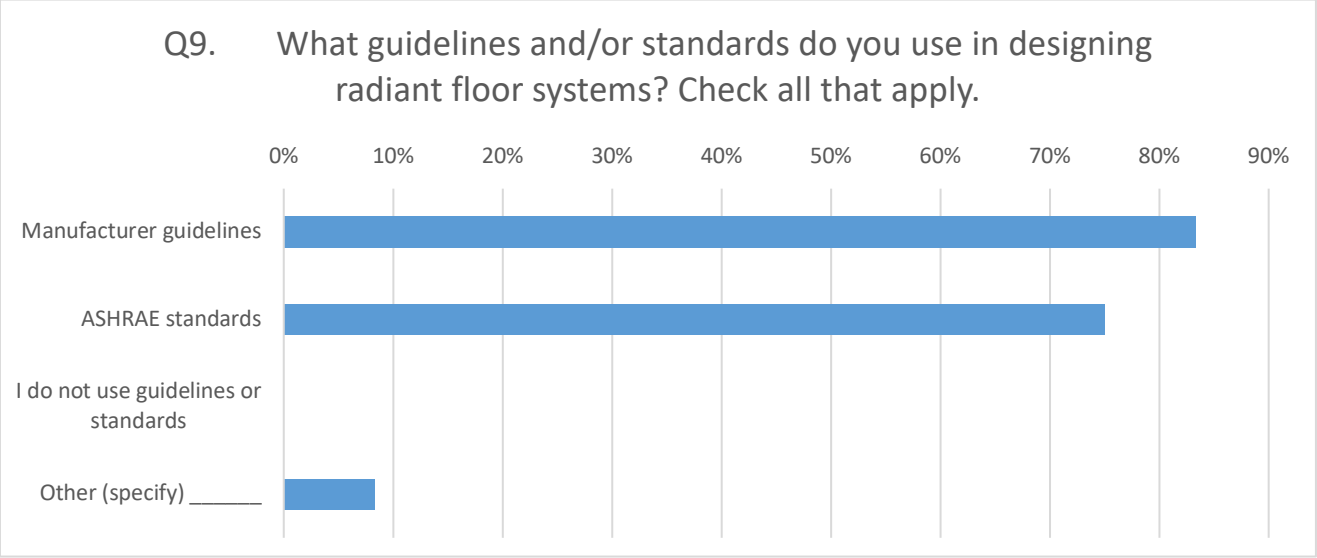
Question 7 asked about the main reason why an expert would choose a radiant system over other types of heating systems. Comfort and energy efficiency were the main reasons given by the respondents, with 91% indicating comfort and 75% indicating energy efficiency. Other answers from respondents indicated that heat pumps and/or condensing boilers were an excellent combination with radiant systems, while others reported choosing radiant systems if there were space restrictions limiting the use of other mechanical systems. It may be concluded that comfort is the main priority, but the energy efficiency associated with these systems is also very important.



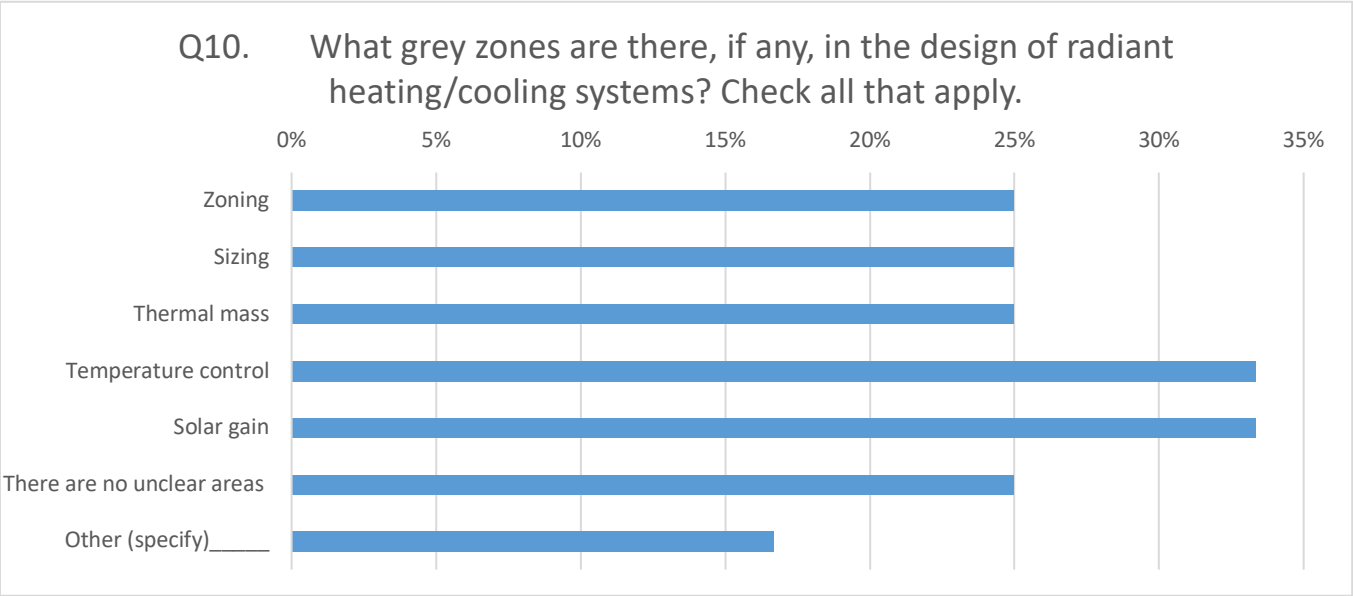
In question 8, which dealt with the type of tool most sought out by the experts for load calculations and sizing of radiant systems, the majority of consultants (75%) used TRACE software. e-Quest and ePlus were chosen in equal numbers by 50% of the experts consulted, while 40% of experts said they used Elite software. A minority of experts (18%) preferred manual calculation.



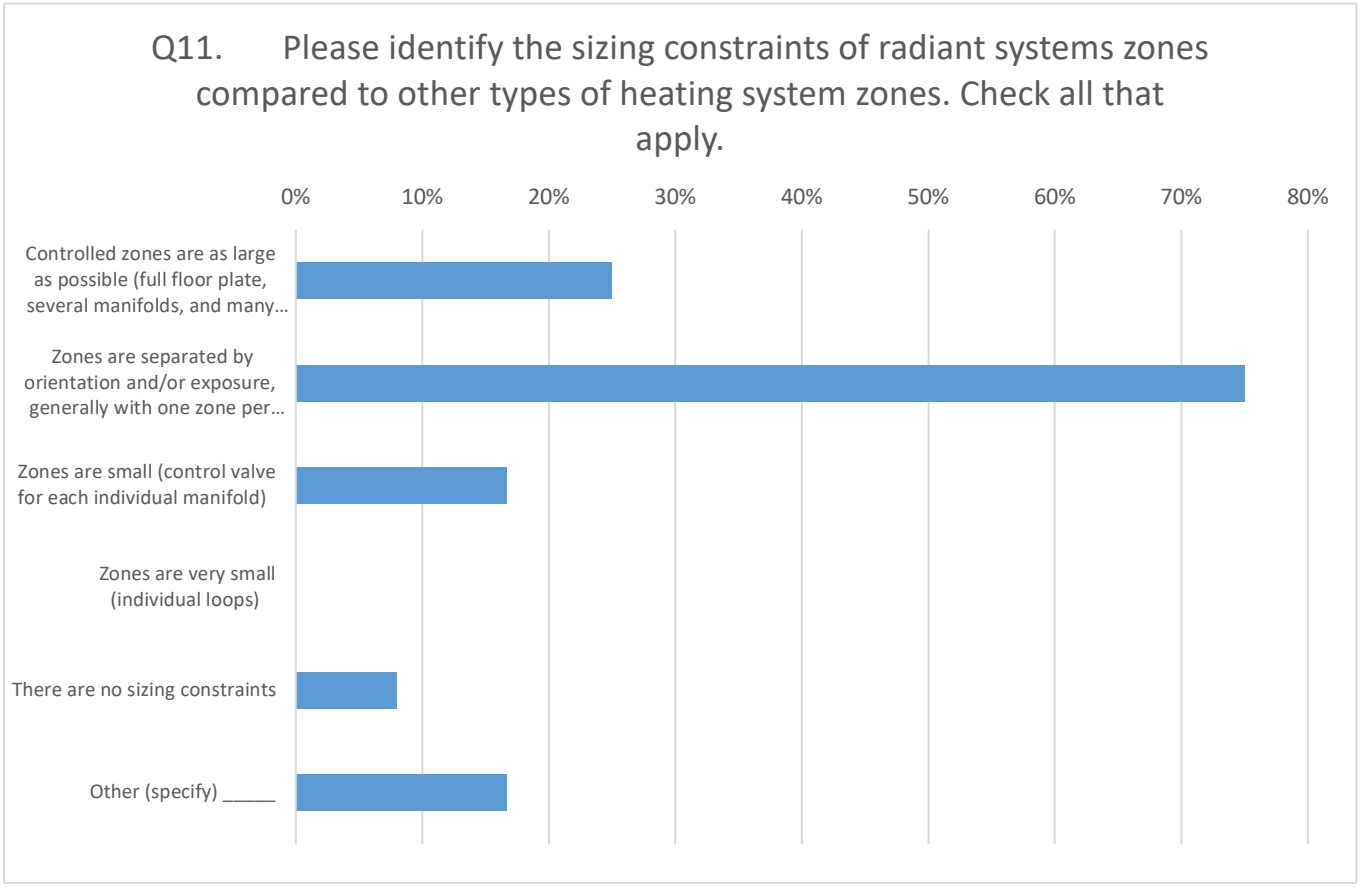

Question 9 asked which guidelines and/or standards the engineers used. Ninety-one percent (91%) said they used the manufacturers' guidelines, but 75% said they used the ASHRAE standards as frequently or exclusively.



Question 10 dealt with the grey zones associated with the design of radiant systems. Results showed that among the following five choices, zoning, sizing, thermal mass, temperature control and solar gain, none stood out in particular. One engineer in four appeared to have some problems with one of the choices offered. Surprisingly, the same ratio was observed with the option titled there are no unclear areas.



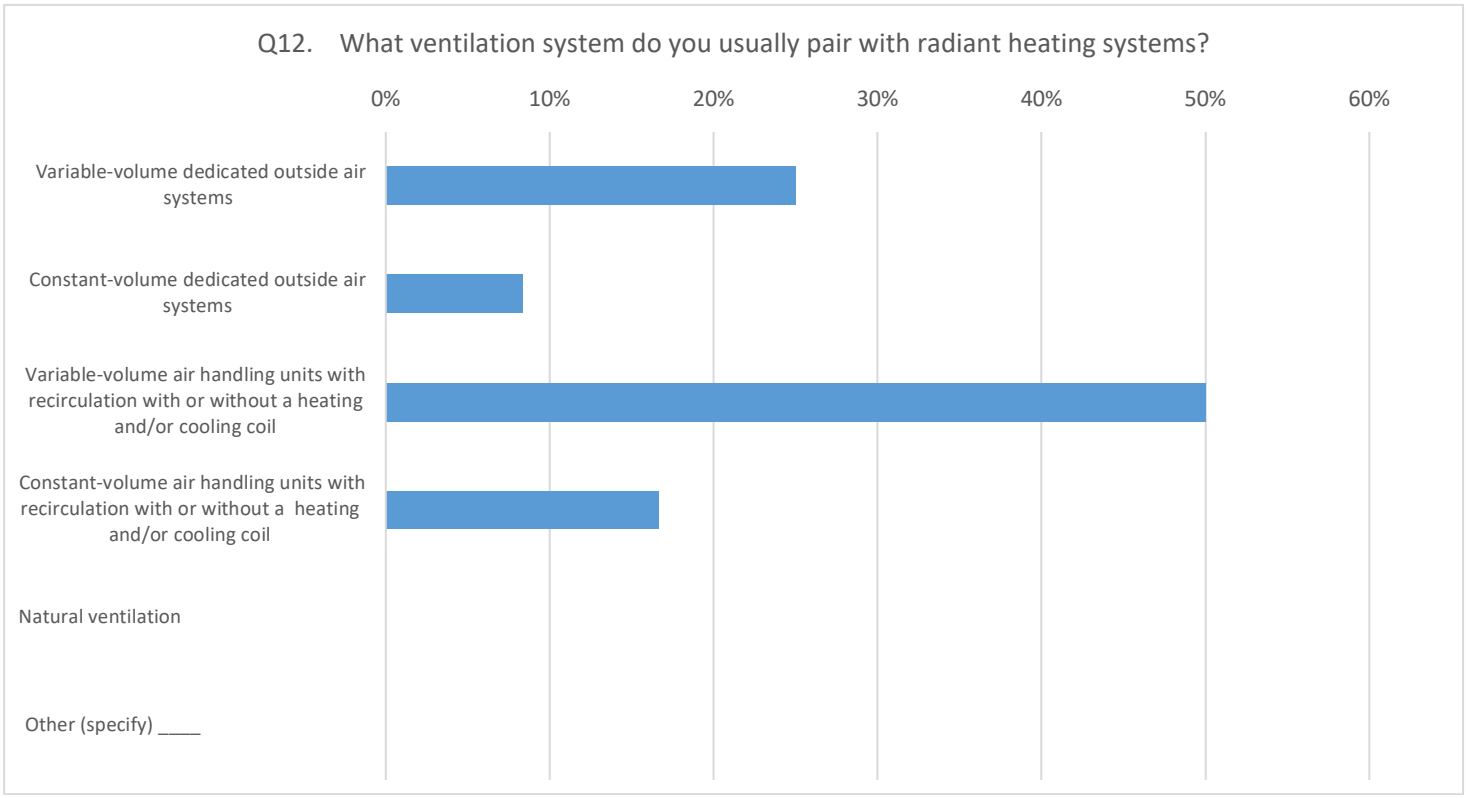
Question 11 focused on identifying the sizing constraints of radiant systems zones compared to other types of heating system zones. Five (5) choices were offered, including large zones, zones separated by orientation and/or exposure, small zones and very small zones with individual loops. Over 75% of respondents indicated zoning by orientation, with several manifolds and loops. Among the other choices 25% answered large zones, while 16% chose small zones with a control valve for each manifold.



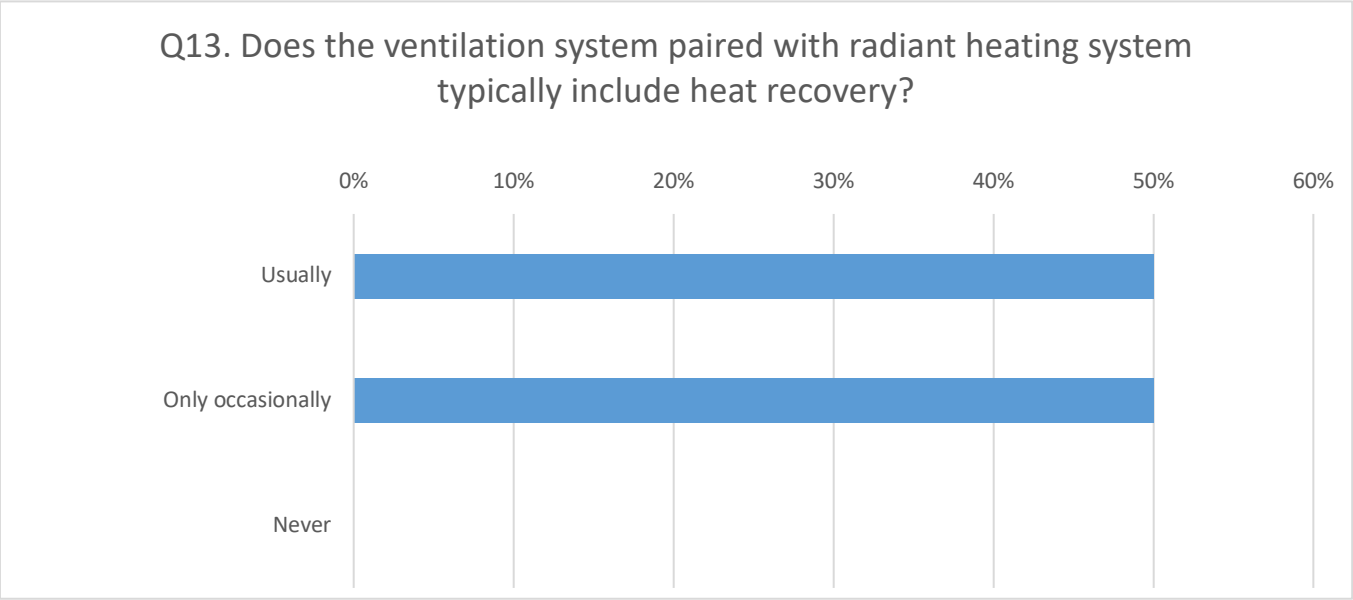
## Questions on ventilation

Seven questions dealt with the choice of ventilation system to be paired with a radiant floor system.

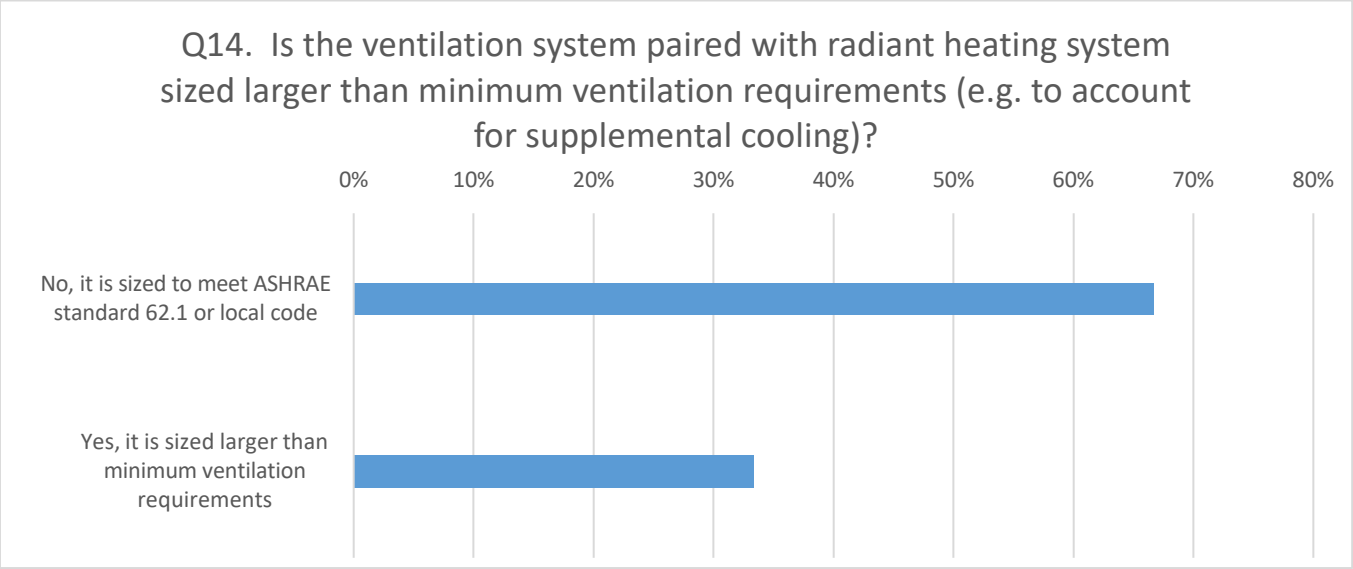
Question 12 asked respondents to identify the type of system most often selected. Fifty percent (50%) of the respondents chose a variable-volume system with recirculation, with or without a heating and/or cooling coil. One hundred percent dedicated outside air variable-volume systems were also chosen by 25 % of the respondents. The other respondents, or the other 25%, chose constant-volume systems, 100% dedicated outside air systems (9%) and with recirculation (16%). Variable-volume systems appeared to be predominant here.



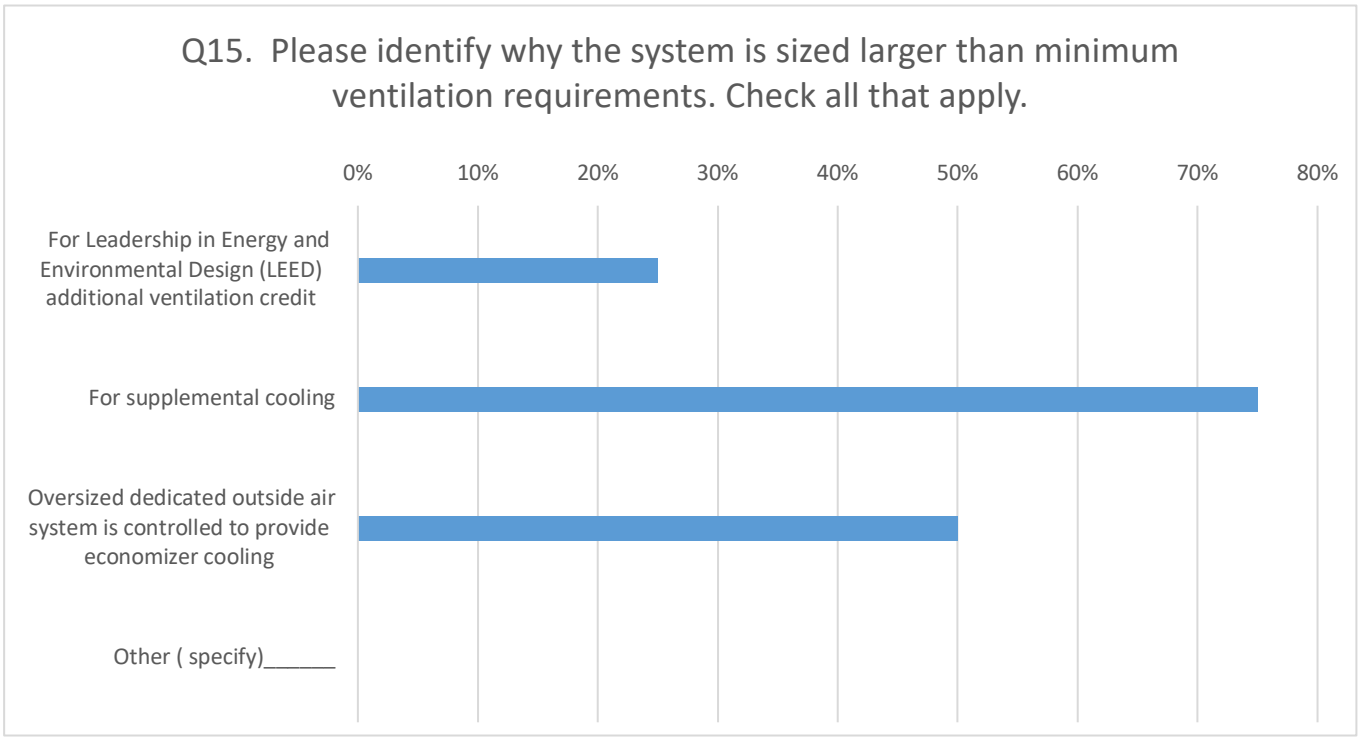
Question 13 asked if heat recovery was considered in the design of ventilation and radiant floor systems, and 100% of the respondents answered yes, one half stating usually and the other half only occasionally.



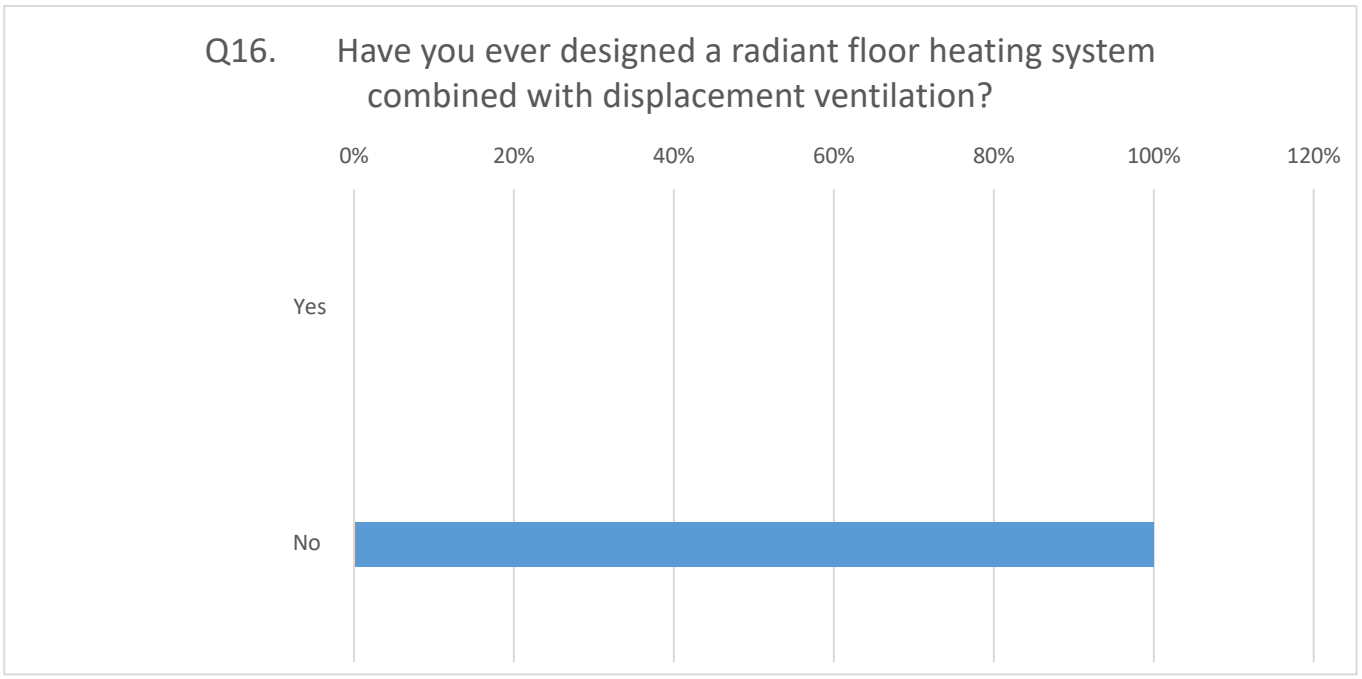
Question 14 asked whether the engineer oversized ventilation systems to account for the supplemental cooling that could occur during heat waves. Two thirds (2/3) replied no to this question stating that the ventilation systems were sized according to ASHRAE Standard 62.1, while the other third (1/3) replied yes. A sub-question that could have been asked then would have been whether the supplemental cooling should be performed only by the radiant floor. According to the choice made by the majority of engineers to this question, it would seem that, indeed, the radiant floor would be expected to meet this occasional load.



For those who answered yes to thepreviousquestion, question 15 asked what the main reason was for oversizing a ventilation system. Seventy-five percent (75%) answered for supplemental cooling, that is, the load that the ventilation system can handle in conjunctionwith the radiant floor capacity. Fifty percent (50%) mentioned that with dedicated outside air systems, it is possible to take advantage of free cooling, while 25% chose to oversize for the LEED ventilation credit.



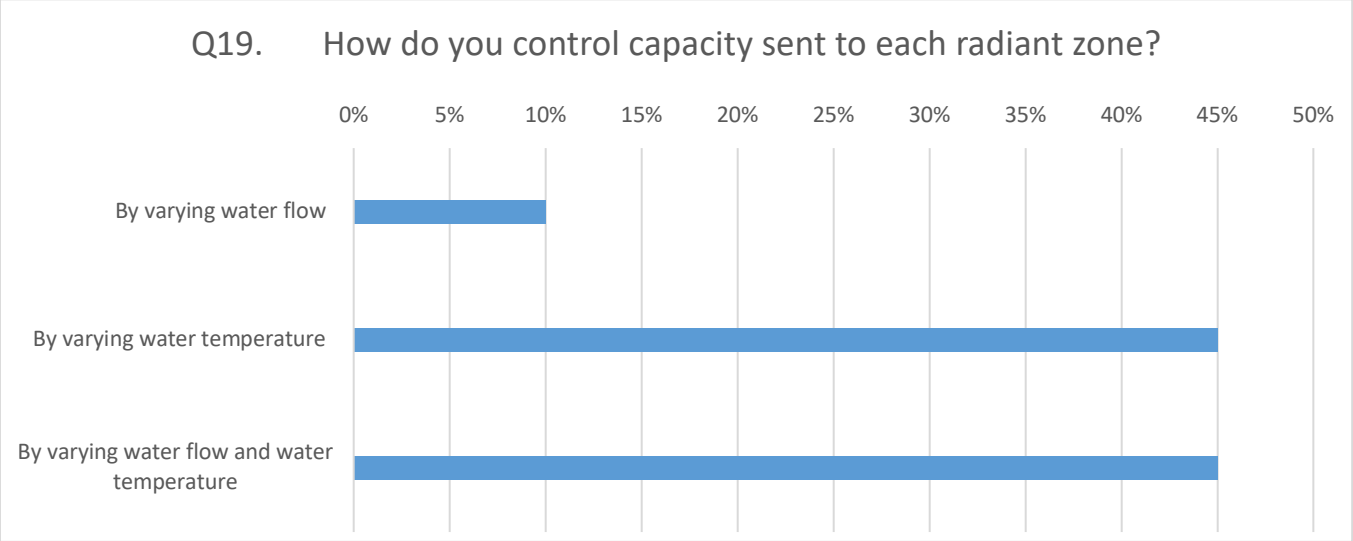
Questions 16 to 18[1], inclusive, dealt with the design of displacement ventilation systems paired with radiant floors. Unexpectedly, none of the respondents had designed displacement ventilation–radiant floor systems combinations, so we can simply observe that these combinations are infrequent and probably not well known by the engineering consulting firms that were surveyed.



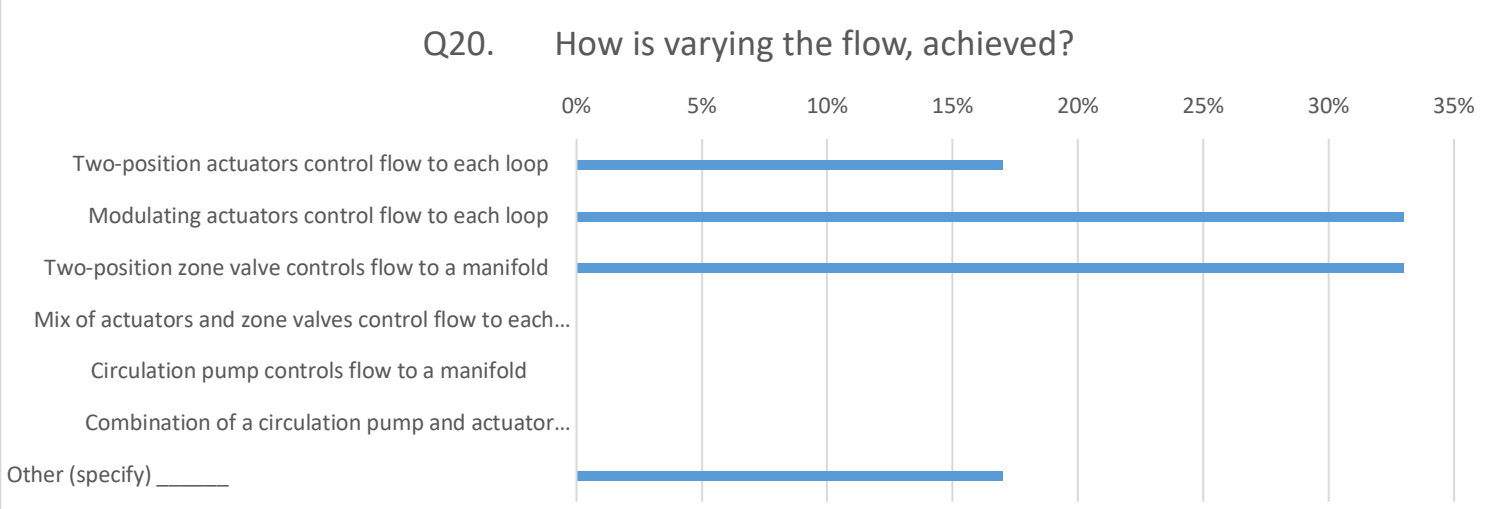

[1] Questions 17 and 18 relating to displacement ventilation were not answered since no respondents had designed a displacement ventilation system.

## Questions on controls

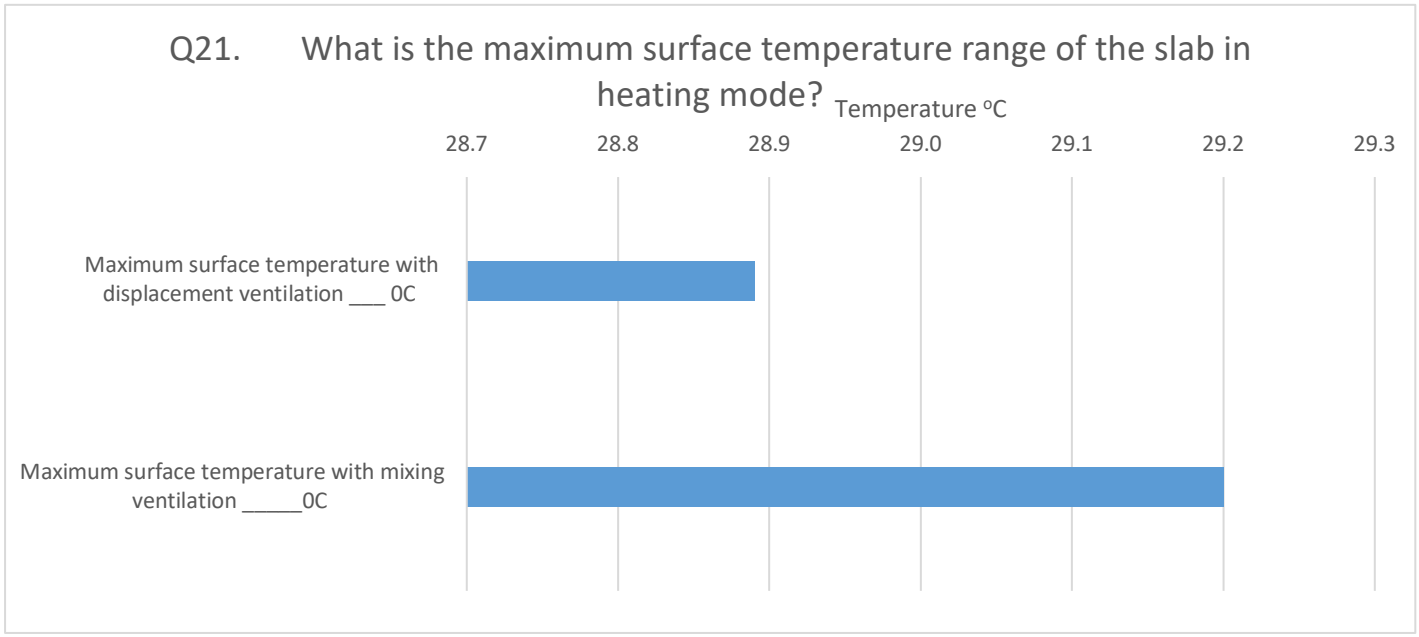
Questions 19 to 26 dealt with radiant system controls. Question 19 focused on the strategy for controlling heating or cooling capacity for each zone. 45% of respondents answered by varying temperature and water flow and 45% by varying temperature only. Less than 10% indicated that they would use water flow only of the radiant heating system.



Question 20 asked respondents to clarify how flow control was carried out. Seven (7) choices were available to respondents but only four (4) were selected. Sixteen percent (16%) of respondents chose to use two-position actuators to control the flow to each loop, 33% of respondents chose to use modulating actuators to control the flow to each loop, 33% of respondents chose a two-position zone valve controlling the flow to the manifold, while 16% chose to use a circulation pump controlling the flow to the manifold.

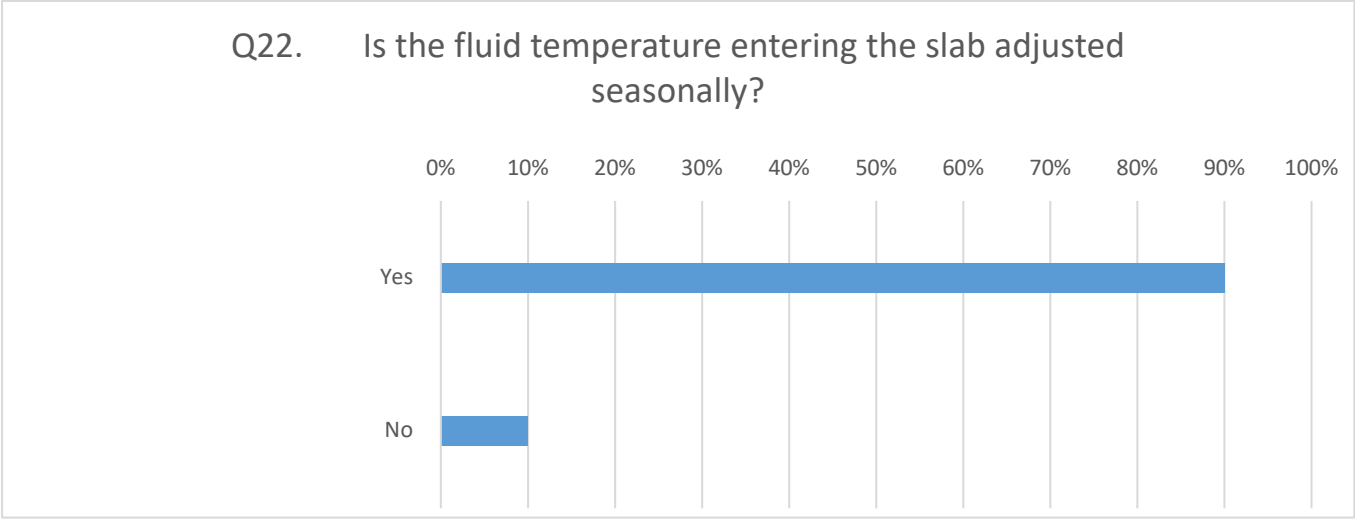



Question 21 asked what the maximum surface temperature range of the radiant floor was when it was combined with a displacement ventilation system or in the case of a mixed ventilation system. The temperatures provided ranged from 18°C to 40°C for displacement systems and from 27°C to 40°C for mixed systems.

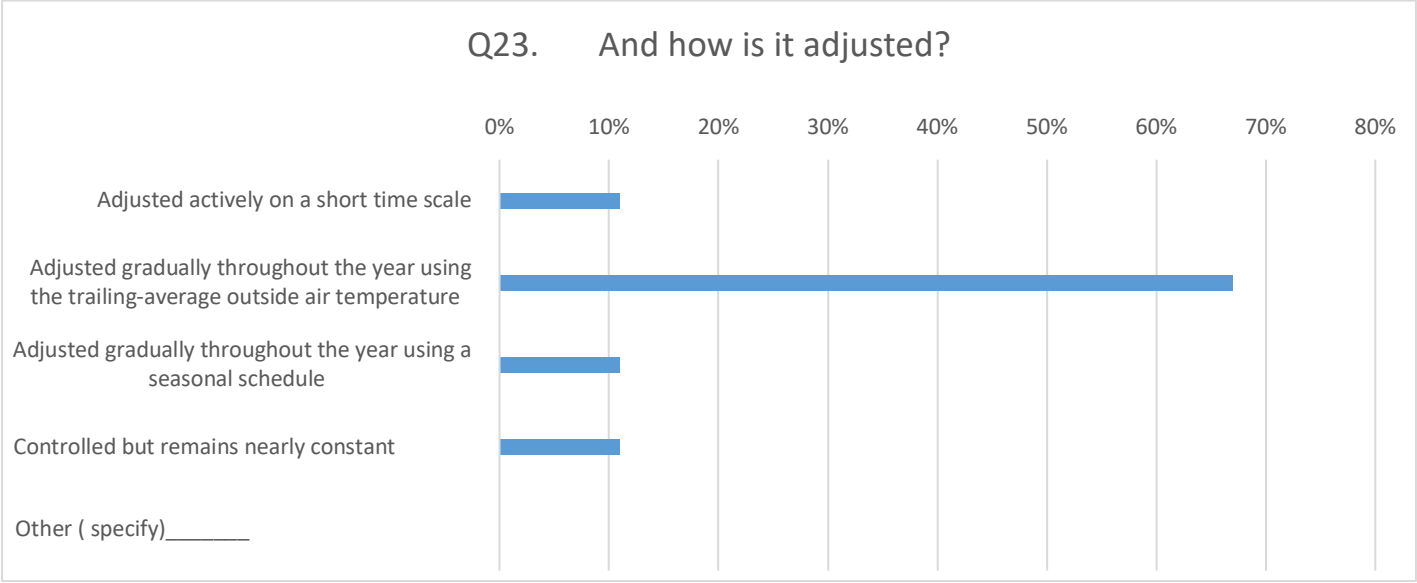


On the one hand, one wonders how experts who have not designed displacement ventilation systems can answer this question and, on the other hand, note that many of the responses provided for displacement ventilation systems are incompatible with the stratification principle underlying this type of system. Consequently, the responses provided for displacement ventilation systems will not be taken into consideration.

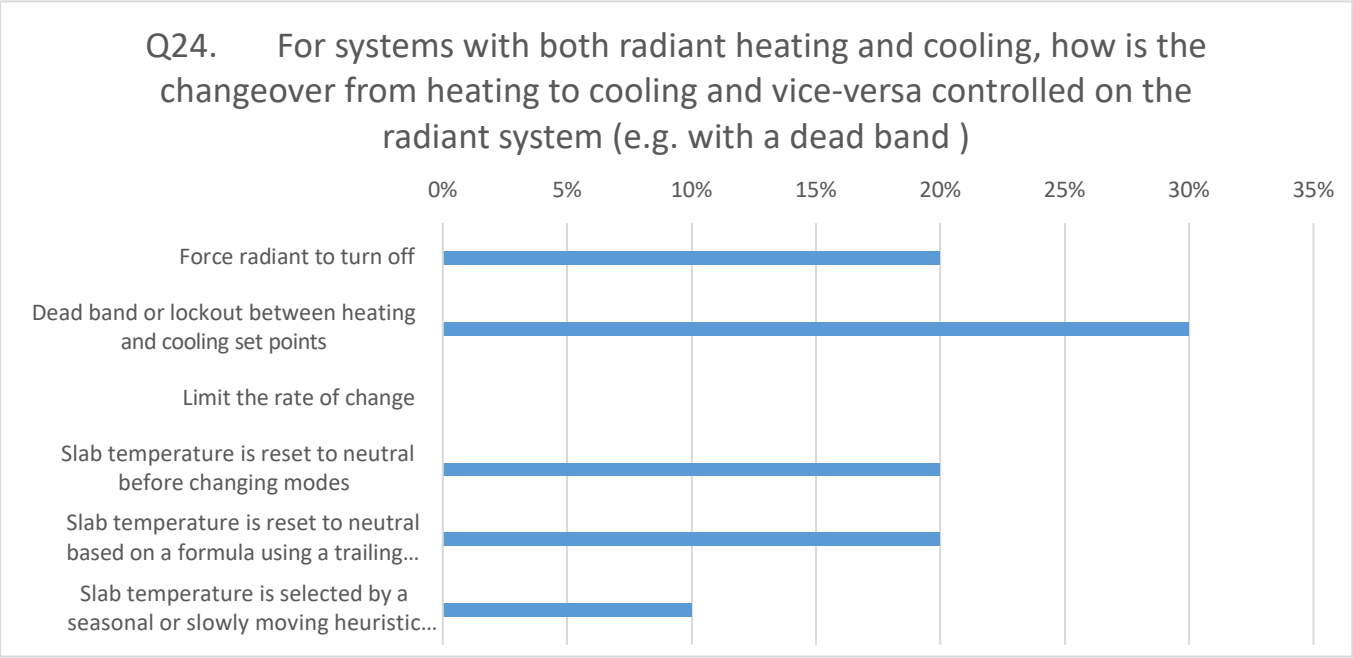
Question 22 asked whether the temperature of the water circulating in the slab was adjusted seasonally. Unambiguously, 90% of the respondents said yes.



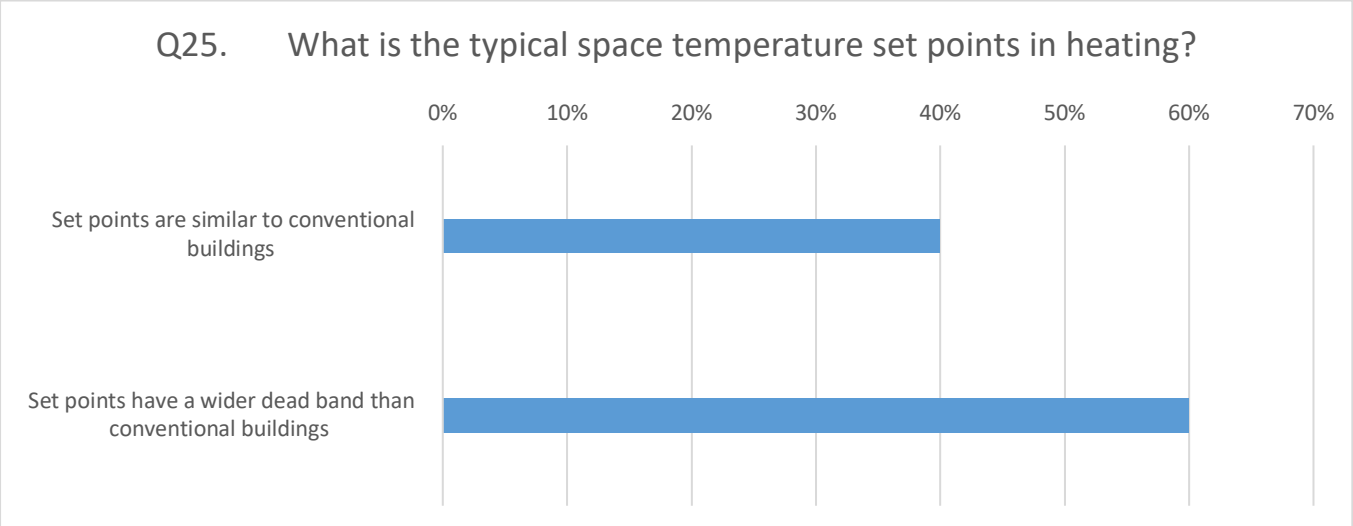

In question 23, which asked how this temperature was adjusted, the majority of respondents (67%) replied gradually throughout the year using the trailing-average outside air temperature.



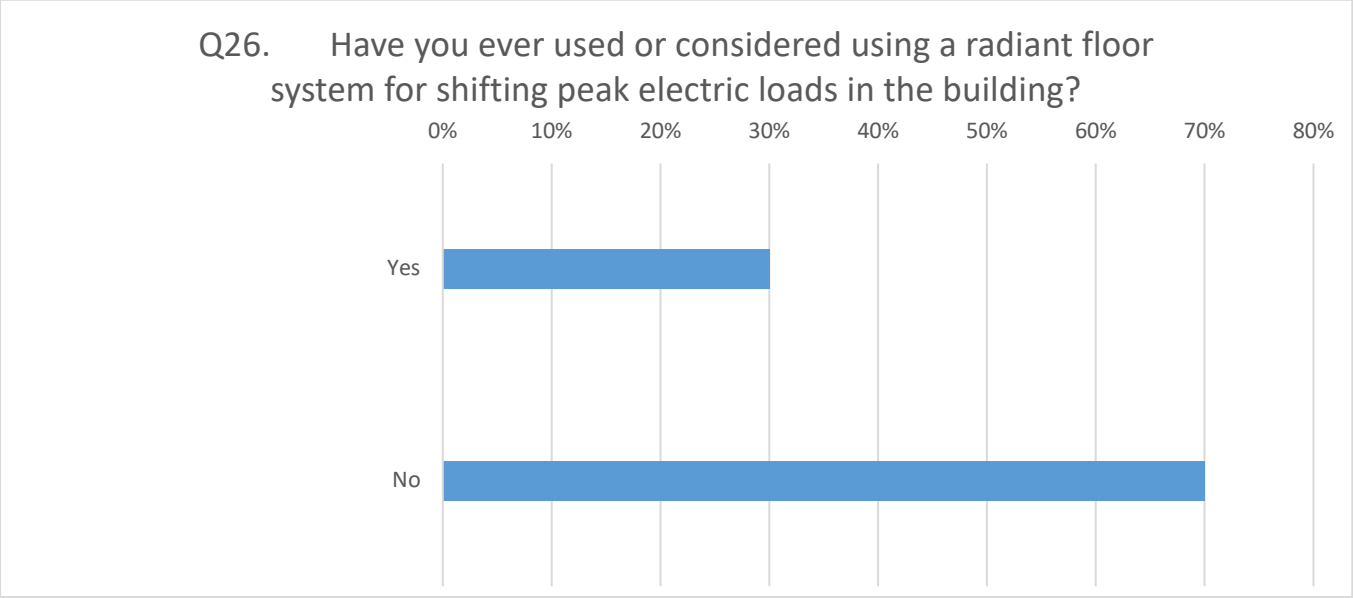
In question 24, respondents' answers were distributed across the various options. As we can see, there was no consensus on this control strategy. This lack of consensus suggests that this issue might need to be studied to determine whether one strategy is clearly preferable depending on the radiant floor–ventilation system combination that is selected.




Question 25 asked what the typical space temperature setpoints in heating mode would be; 40% replied that the setpoints were similar to those of a conventional building, while 60% chose setpoints with a wider dead band than those of a conventional building (considering the thermal mass). Again, there was no consensus.



Finally, question 26 asked whether a designer had ever considered using a radiant heating system to shift peak electric loads in the building; 70% answered no to this question.




## INTERPRETATION

Of the total number of questions that were asked, some showed a clear consensus. In total, a dozen questions showed a consensus, that is, more than two thirds (2/3) of the respondents indicated the same answer.

**List of answers showing consensus:**

In question 3, What type of system have you designed? the majority had designed radiant heating systems only. This is consistent with the Canadian climate, where heating predominates.

In questions 4 and 5 on the design of TABS and ESS systems, respondents indicated that they had designed between one and five TABS systems, and the majority indicated that they had never designed an ESS system (71%). These responses are somewhat surprising but may be the result of the small sample size.

In question 7, For what reasons have you chosen to implement radiant systems over other types? the majority (92%) chose a radiant system for comfort reasons. This answer is consistent with what the literature reports on radiant systems.

In question 8, What design tool are you using to determine the heating (and cooling) loads? 75% responded that they used TRACE software. This software is actually very popular among engineering consulting firms for calculating loads.

In question 11, Identify the sizing constraints of radiant systems zones compared to other types of heating system zones, 75% answered that zones are separated according to their orientation and/or exposure, usually with one zone per perimeter orientation (interior/exterior, multiple manifolds, multiple loops).

In question 14, Is the ventilation system paired with radiant heating system sized larger than minimum ventilation requirements (e.g., to account for supplemental cooling)? 67% replied no, it is sized to meet ASHRAE Standard 62.1 or local code. This answer is consistent with the answer to question 3, where the majority had designed radiant heating systems only.

However, for those who answered yes to question 14, question 15, Please identify why the system is sized larger than the minimum requirements, 75% said for supplemental cooling.

In question 16, Have you ever designed a radiant floor heating system with displacement ventilation? 100% answered no. Questions 17 and 18 about displacement ventilation were not answered. This answer is also surprising since the design of displacement systems is increasing, and the radiant-displacement combination is reputed to be more efficient in the literature (Displacement Ventilation in Non-industrial Premises, REHVA Guidebook). Again, it may be the case that the respondent sample was not representative.

In question 22, Is the fluid temperature entering the slab adjusted seasonally? 90% answered yes.

And in the next question, 23, How is it adjusted? 67% said gradually throughout the year using trailing-average outside air temperature.

Finally, in question 26, Have you ever considered using a radiant heating system to shift peak electricity loads in the building? 70% answered no. Remember that the respondents mentioned that there was a grey zone with respect to the calculation of thermal mass.

*Based on the answers that showed a consensus, we may conclude that the firms that responded to the survey primarily design TABS radiant heating systems only, mainly for comfort reasons. They prefer to use TRACE software for determining loads with the main constraint being sizing of separate zones depending on their orientation and that combined ventilation systems are not the displacement type, nor are they typically oversized, but those that are oversized are oversized to enable supplemental cooling. With respect to control, the temperature of the fluid entering the slab is adjusted seasonally throughout the year based on trailing-average outside air temperature.*

**List of answers <u>not</u> showing consensus**

In question 6, What occupancy types, in your opinion, are most suitable for radiant systems? 50% associated radiant systems with large open spaces, 33% with any type of space and 17% with spaces that are continuously occupied such as classrooms or offices.

In question 9, What guidelines and/or standards do you use in designing radiant floor systems? the results were divided evenly between manufacturers' guidelines and ASHRAE standards. It is very likely that respondents checked both options because these tools are complementary rather than exclusive. The manufacturers' guidelines provide practical solutions for designers, whereas the ASHRAE standards set out the underlying theoretical aspects.
In question 10, What grey zones are there, if any, in the design of radiant heating/cooling systems? all of the choices were checked in equal numbers except for temperature control and solar gains, which each received one additional vote. The difficulty in modelling solar gains and thermal mass were specifically mentioned. The indirect effect of this difficulty can affect the temperature control and optimal sizing of the radiant system. All of these elements are therefore interconnected.

In question 12, What ventilation system do you usually pair with radiant heating systems? 50% indicated that they paired radiant systems with variable-flow ventilation systems with recirculation, 16% with constant-flow systems with recirculation, 25% chose variable-flow dedicated outside air systems, and 8% constant-flow dedicated outside air systems. Even though there was no consensus on one system in particular, systems with recirculation (66%) predominated over dedicated systems. Similarly, the majority (75%) opted for variable-flow systems over constant-flow systems. Variable-flow systems are compatible with the type of space chosen in question 6.

In question 13, Does the ventilation system paired with radiant heating system typically include heat recovery? 50% answered usually and 50% said occasionally.

In question 19, How do you control capacity sent to each radiant zone? 45% indicated by varying water temperature (only), 45% said by varying water flow and temperature, and 9% said by varying water flow only. Control by varying water temperature only is surprising. Could the fact that they were offered this choice of answers have misled the respondents, who may have interpreted this option as being the main means of control rather than the only means?

In question 20, How was varying the flow achieved? 33% indicated that they used modulating actuators to control the flow to each loop, 33% chose a two-position zone valve to control the flow to the manifold, 16% chose two-position actuators to control the flow to each loop, and 16% by using an on/off circulation pump to direct flow to the manifold and a three-way modulating valve to inject more or less hot water into the radiant floor.

In question 21, What is the maximum surface temperature range of the slab in heating mode? The temperatures indicated ranged from $18^0$C to $40^0$C for displacement systems and from $27^0$C to $40^0$C for mixing systems. It was surprising to find values for displacement systems since none of the respondents indicated that they had ever designed one.

In question 24, For systems with both radiant heating and cooling, how is the changeover from heating to cooling and vice-versa controlled on the radiant system? (e.g., with a dead band), 30% indicated a dead band or lockout between the heating and cooling setpoints, 20% said by forcing the radiant system to turn off, 20% said by resetting the slab temperature to neutral before the mode change, 20% said by resetting the slab temperature to neutral based on a formula using the trailing-average outside temperature (average over 3–5 days) and 10% said with the slab temperature, which is set by season or by slowly moving a heuristic control on a scale of days to weeks.

In question 25, What are the typical space temperature setpoints in heating? 60% answered that the setpoints have a wider dead band than that of a conventional building and 40% said that the setpoints are similar to those of a conventional building.

Several questions (40%) showed no consensus among respondents. The numerous grey zones in design had an impact on the choices made with respect to ventilation and controls in particular. It is important, therefore, to target critical elements in the design of radiant systems to reduce the unknown factors raised by the consultants.

## COMPARISON WITH THE RESULTS OF THE CBE/TRC INTERVIEWS

Comparative analysis of the answers to this survey and the results of interviews with the Center for the Built Environment and TRC Energy Services

The following questions were asked both during the CBE/TRC interviews and on the survey conducted by CanmetENERGY

Q1 What is your title?

In both cases, the majority of respondents identified themselves as engineers.

Q4 In a thermally activated building system, the tubing is integrated into the building's structural slab or into the surface slab if it sits on top of the structural slab without any insulation between the two slabs. Based on this definition, how many systems of this type have you designed?

The survey answers indicated that most had designed between one and five TABS systems, whereas the interviews revealed that four (4) had designed between six and 10 systems and four (4) had designed more than 20.
The preselection of candidates for the CBE/TRCinterviews may partly explainthissignificant difference. The survey was conducted among approximately 20 firms, and we had no other preselection criteria apart from ensuring that they had HVAC expertise.

Q6 What occupancy types, in your opinion, are most suitable for radiant systems?

The majority of survey respondents chose large open spaces such as lobbies, atriums, museums and airport terminals, while the interview results indicated that choices were split between suitable for any type of space or when cooling is predominant.

Note that the predominant choice for cooling was not offered in the survey.

Q11 Identify the sizing constraints of radiant systems zones compared to other types of heating system zones.

The answers to this question showed a strong agreement between the survey answers and those given by the interviewees. The majority of respondents opted for separate zones depending on their orientation and/or exposure, generally with one zone per perimeter orientation (interior/exterior, multiple manifolds, multiple loops)

Q12 What ventilation system do you usually pair with radiant heating systems?

The answers given by the survey respondents differed from those given by the CBE/TRC interviewees. The majority of survey respondents (50%) opted for a variable-flow system with recirculation, whereas all the CBE/TRC interviewees (100%) opted for a dedicated outside air variable-flow system. Despite this strong preference for variable dedicated systems or those with recirculation, the survey respondents' second choice was for variable dedicated outside air systems (25%), while the interviewees chose constant-flow dedicated systems and natural ventilation systems in equal numbers.

Q13 Does the ventilation system paired with radiant heating system typically include heat recovery?

For this question, the majority of interviewees said yes, usually, while 50% of survey respondents chose usually and 50% chose occasionally.

Q14 Is the ventilation system paired with radiant heating system sized larger than minimum ventilation requirements (e.g., to account for supplemental cooling)?

Here again, the survey respondents' answers differed considerably from those given by the CBE/TRC interviewees. The majority of survey respondents (67%) chose to size the ventilation system according to ASHRAE Standard 62.1, while only 18% of the interviewees chose this option. The majority of the interviewees chose to size larger than the minimum standards to increase cooling capacity or to take advantage of the LEED ventilation credit.

Q20/21How do you control the amount of energy provided to each radiant zone? How was varying the flow achieved?

In the first of these two questions, the answers provided on how to control the amount of energy in the radiant zones were compiled only for the survey respondents (the CBE/TRC did not indicate whether respondents control it using water temperature only). Forty-five percent (45%) of survey respondents reported varying both water flow and temperature, and a similar proportion the temperature only. The control of flow offered several choices ranging from a simple two-position on/off control to the combination of a circulating pump and flow control using a modulating actuator. The CBE/TRC answers showed a preference for a two-position control (60%) over control by zone using modulating valves (40%). The survey respondents showed a similar profile to the CBE/TRC interviewees. Thus, one half (50%) chose a two-position control and the other half control by modulating valve.

Q23/24 Is the fluid temperature entering the slab adjusted seasonally? How is it adjusted?

In the first question, 90% of the survey respondents indicated yes, the fluid temperature was adjusted seasonally, while 100% of CBE/TRC respondents answered yes to this question. In the second question, 67% of survey respondents and 45% of CBE/TRC respondents indicated a preference for controlling the temperature gradually over the year based on the trailing-average outside air temperature.

Q25 For systems with both radiant heating and cooling, how is the changeover from heating to cooling and vice-versa controlled on the radiant system? (e.g., with a dead band)

This question offered several choices, and both the survey respondents' and the CBE/TRC interviewees' answers varied. The answer of a dead band or lockout between the heating and cooling setpoints was the one that was selected by a small majority of all respondents.

Q26 What are the typical space temperature setpoints in heating?

In this question, 60% of both the survey respondents and the CBE/TRC interviewees indicated that the setpoint has a wider dead band than that of a conventional building.

We found that among the 13 questions applicable to the survey respondents and the 11 questions applicable to the CBE/TRC interviewees, there was a significant amount of agreement. Only the answers to questions 12 and 14 differed significantly.

## Conclusion

The objective of this survey was to better understand the aspects of the design of radiant systems with which engineers are familiar compared to those that may require a better understanding. As noted, there was agreement on a number of questions, that is, about 50% of the total, not only among survey respondents but also between survey respondents and the CBE/TRC interviewees. Nevertheless, the other 50% showed a high degree of variability in the designers' choices. The differences that emerged on some of the questions reveal either inexperience in the design of these systems or a lack of understanding of the effects inherent in radiant systems such as the thermal mass, illustrated perfectly by the temperature range of the slab surface indicated in question 21. In addition, the noted absence of a displacement ventilation system paired with radiant systems demonstrates the need to inform the community of this possibility and of the advantages associated with this type of combination.

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