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Rosemary Bartlett: Welcome everyone. I'm Rosemary Bartlett with the Pacific Northwest National Laboratory, and I'd like to welcome you to today's webinar: Low-Rise Multifamily Code Compliance Study Results. Now without further ado, I'd like to turn things over to Bob Davis at Ecotope to begin. Bob?

Bob Davis: Hi, everybody. I'm Bob Davis from Ecotope. I'm a senior research engineer. And we are glad to be able to present today the main points from the study. There's a whole set of things we can discuss, and we'll hit things at a pretty high level, but we do encourage questions, recognizing that we may have to follow-up on some of them, too, at the end. Next slide please, Rose. We'll kind of go through the context of the study, goals and objectives.

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Look at some of the notable results from the data. And there's several, several groups of data to look at, and then have time to have questions. Next slide, please. This is a team effort. We were the primary contractor, worked on setting up the sample frame and the data collection process for the main study. But we could not have completed the work without a great deal of help from very high quality partners. The Center for Energy Environment in Minneapolis, Slipstream Consulting based in Wisconsin.

And, also, we received a lot of help for a kind of parallel study that was part of this on air tightness from Energy Conservatory, both the in kind and donation –

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…or loans of equipment, and also analysis assistance because – and we'll spend some time today. David Bohac from CE will present results of this parallel study and air tightness. And we believe this is another area of great interest to folks in they're looking at this this building sector. Next slide, please.

[Side conversation about audio]

What I'm gonna do is actually turn this over to the study's sponsor, Jeremy Williams from the Building Technologies Office to kind of set the stage, and I'll return to provide more details on the buildings we looked at and the sample frame.

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Jeremy Williams: All right. Hey, there. Thanks, Bob. I hope everybody can see me and you can hear me okay. As Bob mentioned, I'm Jeremy Williams. I work for the Building Technologies Office of the US Department of Energy. And I wanted to talk just a second about why we do these types of studies, why we think they're important kind of where we stand with our broader field study effort.

Field study is not just multifamily, but single family residential and commercial have been a big part of our project portfolio in recent years, and actually dating back even further. So there's some context there they want to relay so that everybody can understand sort of where we are now and where we're headed, and really the underlying value these types of studies. So what we set out to do, why it's important.

The goal, the original goal was sort of three-fold. We were trying to set out, you know, first, to document baseline design and construction practices in the multifamily sector. Multifamily, a lot of times, gets sort of stuck in the world between residential and commercial.

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There are several aspects that are unique to multifamily. And so when we started this field study effort several years back, you know, dating back to even the 2014 timeframe in the current rendition, we started with single family. And w quickly realized that to adapt this to certainly commercial, but even multifamily, there is a certain amount of adaptation of field protocols, data collection instruments, and kind of the general approach that we needed to take a look at. And so that's what this project, which is a pilot study, was really intended to do.

But in doing that, the goal was to get back to the same place we started with the single family study, which was to document those baseline design and construction trends, and for energy efficiency measures in particular. Two, the end game here is really targeting areas for improvement. Not just going out and look at compliance rates and things like that as previous studies have done, but really trying to get to the question of: "Okay. Now, what we do about it?"

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And for us, you know, from the DOE perspective, that's really about education and training programs, workforce education and training. There are a number of different types of code-related workforce training programs out there. They typically take the format of training builders, designers, code officials, and the like on all things with the code. The state level code, the model code, whatever it might be, and sort of a blanket approach.

Anybody who's been to a co-training has probably had the experience of you go through the code change-by-change. Talk about what's new versus what's old or what was there previously. And we really – as a lot of our analysis is shown, not all measures are created equal. And so we're really trying to drive towards an approach where we had a strong feel for things like bang for the buck. You know, if you've limited time to focus on key measures, what are those key measures to have the largest direct impact on energy efficiency, you know, particularly for the multifamily sector in this case.

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So that was the second piece. And then third was rolling it all up. You know, looking – this approach is really designed to be sort of bottom-up, but also top-down. And by bottom-up, I mean empirical data observations direct from the field, but also reconciling that with some of the overarching policies including codes, you know, reason states adapt codes in the first place, which is energy efficiency. So how do you equate individual technologies or measure observations in the field to statewide energy consumption?

And if you think back to where some of the compliance studies that even DOE has funded in the past, we didn't fully make that connection. So that's the third part is getting back to quantifying the related savings potential. So, again, that savings potential, whether, you know, energy dollar cost savings, or environmental impacts, it's sort of that savings left on the table.

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And we're talking savings on opportunities based on codes that are already in place today. So what are those worth? Okay. And so that's kind of what we set out to do in a nutshell. So the basic tenets of that are creating that methodology that would enable these types of studies in the multifamily sector. Establishing that empirical dataset, which didn't really exist or didn't exist at least in this manner. And also the outputs, which are equating them to things that can be targeted by workforce education and training programs, but also rolling up to that overall impact.

So at this point, we really accomplished what we set out to do with this multifamily pilot study. I'm calling it a pilot because it was limited to four states. We created the methodology as part of the project, and then we tested the methodology in the field.

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And so we're pretty eager. This is the first time we've been able to present the entire set of results. Not just preliminary results, but the entire set results in the final report and have the methodology, the publications, the data collection instruments, and the findings to share with you all. So this is the first look at that. And then as Bob will talk more about, those are available today. You can go to our website at Energy Codes dot-gov and access those.

Just real quickly, what happens next? So it is a pilot study, which means we're testing an approach sort of with the intent of developing something others, and probably being states in this case, could follow. So developing that methodology, protocols for sampling data collection, field data collection I should say and analysis, establishing that empirical dataset of typical design and construction trends for energy efficiency measures as related to code. And then, you know, publishing this initial set of findings, which is what we're doing today.

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And so we're there. What we want to do now is we want to work with additional states who are interested in conducting multifamily studies so of their own. And I say multifamily because that's the focus today, but also in addition, you know we have single family and a new commercial approach that is out there and will be available shortly as well. So it's sort of one piece of that larger puzzle. And then from the DOE perspective, you know, we wanna encourage states to conduct these types of studies on somewhat of a regular basis, you know, every three to five years.

Because we think they're really useful for helping states, you know, document and validate what's going on with their codes and what portion of the impacts of those energy efficiency impacts are savings left on the table they're being achieved because that tends to change over time. But also, and probably most importantly, to inform those ongoing workforce education and training programs that most states have been in one form or another…

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…you know, helping them really hone in on specific things that comes straight from data from their own projects in the field, and can illuminate what are the areas of emphasis that we should focus on from a training standpoint. You know, what needs more attention than others because it tends to be a lot of the same things across states as Bob will probably tell you. So, anyways, Bob, I want to say thanks to you and the project team for hosting this call sharing your results with everybody, but also for everybody out there who's tuned in today and is interested in the results and learning more about what's going on with these studies. So, thanks. And Bob, I will pass it back your way but happy to stick around and answer questions later as well. Thanks.

Bob Davis: All right. Excellent. Thank you very much, Jeremy. It really sets the stage well. I'm gonna return to the deck here…

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…and we'll kind of go through a little more overview and how the sampling was set up and some details on data collection and so forth. And then we'll kind of step through notable results, others from my office, and our partners will discuss those. So just looking here. Yes, there's a whole suite of codes out there that apply to different parts or our built environment. And in this case, we're kind of right there in the middle. And the interesting aspect of this, as well, one interesting aspect, is that we have a combination of common areas as these sites, usually anyway, not always, that might or might not be subject to the residential code. But then we have the bulk of the square footage of the sites covered typically under residential codes.

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There's some variation between states on how those codes are applied, but that's a pretty good organizing principle for low-rise multifamily. Next slide, please. And as Jeremy pointed out, there's been a real shift in focus from, well, I guess, I would call it more a prescriptive check-the-box approach to codes to try to get at the sort of the performance aspects of the codes, like what matters most if it's not followed in how the building is built, and how can that be affected.

This work is – this at this approach is now getting to be, depending on who you talk to, a better part of 10 years old. And DOE's emphasis now is to really try to get into this and see what's possible and how can things be moved more in that direction.

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And so the low-rise sector, there are possibilities, and it's just a matter kind of seeing what we get in different states, and then looking at opportunities for improvements and how you there. And so I guess let's go to the next slide. So the combination of efforts in this this study was as outlined here. First, looking at the actual characteristics in the buildings. Kind of a two-part process where you first look at the as built plan sets for the buildings, and gather information that way. And then go out in the field and actually look at what was installed through a physical review. We also collected, in some cases were available, energy usage information, but that wasn't a major focus here.

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We ended up using the actual characteristics in the context of a whole set of simulations of a building prototypes in the different climate zones that represented in the states and the study, varying from kind of mild marine climates to much colder continental climates. A parallel study, the middle piece here, the green piece, I guess we call it, is the looking in detail at air leakage in a set of these buildings. A much more complicated process than testing single family. This has to do with just the size the buildings, also with how living units are connected, whether they are connected by common areas, or not connected. At least – well, if they are connected unit, but they don't have common areas between the units. That's a whole another issue.

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And we'll get into that a little later in the presentation in some detail, but this is a very active topic in multifamily right now. A lot of effort and interest trying to come up with the testing procedures which are useful in determining energy savings opportunities and also indoor air quality implications, unit-to-unit leakage, and unit to common area leakage, and so forth. And another aspect to what was looked at on the right: market research. Even if we have a technical understanding of the buildings, if we don't have an understanding of how the building is getting built, who makes decisions how the codes are understood by those people, and so forth, we can't necessarily make a lot of change. And so a very important part of this work was looking out there, and through structured interviews, talking to key players in the low rise multifamily sector.

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Architects, builders, others involved in the process. And so that's a very, very interesting and key element of, you know, getting energy codes to really stick and improve. Next slide, please. Well, in certain parts of the United States, low-rise multifamily is a major aspect of what's being constructed. Certainly around and in main metro areas, it's very, very prevalent building use type. Almost 30 percent of new residential units are, in fact, multifamily buildings across the United States. And the definition here is, of low-rise is three floors or less above grade.

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So a very large majority of units that are constructed in multifamily fall into this category. So this obviously is an important sector to look at, maybe one that people hadn't thought about as much, but just looking at these statistics very, you know, central to energy usage and the experience of a lot of people who are moving into new housing in the United States. Next slide, please. For this study, new meant three years or newer. Now, the sample frame here was given how long these things take to get going, and so forth, was back a few years. And we'll look at the codes that were involved in these construction projects.

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But new means not only in the last two years related to 2020, but more in the 2013 to 16 range, roughly, maybe in that range. And, again, up to three stories above grade. Five or more units. Mixed occupancy means, in many cases, there was a – or in some cases anyway, there may have been commercial space on the ground floor depending on the site. The study did not look at any single family homes, or duplexes, or townhomes, or anything that's, you know, four stories mid-rise or high-rise, so just to make clear what we looked at. Next slide, please. One more thing to note here, and this has implications both for the basic energy characteristics, also predicted energy use, but also especially for the air tightness testing.

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Two-man construction styles in the sector. One we call garden style, meaning – I don't even know where that term came from but *[laughter]* what it means is we have exterior entry to each living unit. And the corridors, such as they are, are essentially open to outside. If you look in the middle that picture on the left, you can see could see it all the way through. On the right – well, I should say these buildings are more common in milder parts of the US,, however they still are certainly being built in in colder parts the US.

On the right, the common entry, which has an enclosed space, like an atrium or something similar, where a living unit door, the primary doors, open from into. So that facilitates a different type of air leakage test.

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You can use the common spaces as a communication point, and that's helpful in terms of the speed of doing tests in that type of construction versus garden style. But that's just – this is important to keep in mind because a lot of the summaries of the data are broken out by these construction types. Next slide, please. This slide has too much information on it. *[Laughter]* But I will mention that there's a very detailed discussion of how the sample design was derived. And in the report, there's actually an appendix which describes in detail how it was done. And I'll go through a few of the high points, but just because of time, we can't get too far into them. The main data source just to start with, to get sites that could be surveyed, was the was Dodge Data.

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And we worked with PNNL on that. And the significance of that is as states work through doing their own studies in the future, it seems a good mechanism to work with the national labs and with these datasets to kind of get started. And one goal this project, I think was pretty well realized, was to come up with a pretty solid methodology to, you know, get sites in, and design a sample, and do the recruiting, and so forth and so. Yeah, the construction timing for what was called new was 2014-2016, during those years. So just to keep that in mind.

We did end up with – well, actually, let me delay that. To actually get to sites and get information and contact information after we have the Dodge ID…

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…we have to work with local jurisdictions, co-jurisdictions, to get contact information and then start making contacts, come up with the actual recruiting lists because the sampling will – you inevitably, of course, not get all the sites that you thought, so you have to have a bigger list and you ran a recruiting from that list. We use a building approach to actually start with the recruiting. But, of course, within the building, there are actual units. And the units are where the bulk of the time is spent looking at characteristics, whether on the plans or in the field.

So that's important to keep in mind. It's sort of a two-step process as far as, you know, identifying buildings and then also going out and looking at units. This statistical criteria, sort of the target was 90/10, pretty typical, conference intervals, and so on.

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And, also, as part of the sample sizes, it's important to note that there's a whole set of physical characteristics that you can look at within these buildings, you know, both continuous variable type ones, like the size of the buildings, and lighting power densities, and so on. And also binary variables such as does it have this type of heating system, that type of heating system? But kind of looking at RECS data, you know, Residential Energy Consumption Survey data, and looking at different summaries of these things that kind of settled upon a coefficient variation, and average one, anyways, of about .66. Some cases, this can result in higher levels of precision. In other cases, less. But in general, this is kind approach was thought to be a reasonable one for this set of buildings.

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And we ended up with about 25 buildings per state. We'll look at which states in a minute here, and about three to four units per building being sampled. Next slide, please. We did the work in Illinois, Minnesota, Oregon, and Washington just because of the where people live and where these buildings are being constructed. Most of the work is concentrated around larger cities and some smaller cities. And as it turned out, in some cases, we ended up serving a near-census of all eligible buildings in certain parts of state. It's just kind of how it worked out.

But you can see Illinois in upper left, a lot of the work concentrated around the Chicago area, some downstate. Minnesota, also around the major Minneapolis area, but some of the representation is around the state.

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Oregon, Portland, and the Willamette Valley. Washington, Seattle, King County, and then some on the eastside of the state around Spokane and a few other sites around the state. Next slide, please. As mentioned, yes, kind of a two-stage sample design. We start the building level, meaning the overall complex. That's where the address is. It includes both common areas and living units, in some cases, depending on the building type. And then the secondary sampling unit was the actual being in the living cells. And, generally, that we would select three or four units per site.

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And this was someone up to the field surveyor, but the idea was to make it that as random as possible to improve the representativeness of the data that were collected. Next slide, please. Just an example here of kind of the key items that were being looked at in both the plan review and the field review. The building thermal shell insulation levels. Heating/cooling systems. Hot water system and so forth. The common also was looked at. The reason it's broken out is because in most cases, that was covered by a different code. Not always, but often.

If you look on the code references, you can see that we have – you know, the R references and the C references to residential or commercial, and these are all referenced the ICC, International Energy Conservation Code.

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And depending on the year and so on, and we'll see this the summaries, it was an older version of the code, even as old as '09, I believe in some cases, or up to a newer version which is the 2015 ICC as implemented by the states. Also, lighting obviously was with a key thing, and that appears in both common areas and in the living units. But these are the things that were returned to and looking at the physical characteristics because they're the major levers on affecting energy use in the buildings. Next slide, please.

Just some more – this is more to show the kind of the range of coefficients and variation for these different variables. And just to give a sense of how things, you know, vary by parameter.

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It's not put up to start a long scholastic discussion about them, but just to give you a sense of how things would look depending on what you're focusing on. And, yeah, this is discussed in considerable detail in the body of the report, and I encourage people to go there and take a look. And if there are additional questions, I'll certainly answer those as well. Next, please. Let's see. I'm not sure what we do here. *[Laughter]*

Rosemary Bartlett: It's time for a poll question.

Bob Davis: Rose knows what to do. *[Laughter]*

Rosemary Bartlett: It's time for a polling question. So I'm going to launch the poll. This question relates to the attendee's location.

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So if you could pick the region where you are located so we can get a sense of who's participating today, we'd appreciate it. We'll give you a few seconds to do that. Okay. I'll close the poll. Show everybody the results. And there's the mix. A pretty decent mix across the regions. Thanks very much. We appreciate that.

Bob Davis: Okay. I'll try to wrap up here pretty quickly. But I think I mentioned most of these things. The actual data collection was a two-part process.

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One was to look at plan sets in advance of going out to the site to kind of pre-populate a spreadsheet-based tool that was assigned for the project, and then go out in the field and look at actual installed characteristics and keep a record of that as well. That's kind of been the way that a lot of code evaluations have been done over the relatively recent history and across sectors. And it provides a very well-organized way to both record the results and then also start to move the data collected into other parts of the analysis, including energy usage estimates and that sort of thing. So I think that's enough to say on this one. Next slide, please. So we ended up with about, you know, close to 25 buildings in each of the areas.

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The recruiting success rates are shown. We had a variety of issues in terms of recruiting depending on how easily it was to contact buildings if we had full information and so on. So that meant, in some cases, the final recruiting rates were pretty, but that's pretty normal for code studies. And also represents, in some cases, how Dodge Data differs from actual jurisdictional data. There are a variety of things that go into these databases that don't always lead to a full complete, I would say.

As mentioned before, I guess I said 2009. Maybe that's too far back. I thought we had a few – a couple that were that far back, but 2012 and 2015 were the most common ICC versions that came through in terms of how the sites were permitted and constructed.

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Different states have their own variations on the ICC depending on what the components are. And so that's important to remember. And as I've mentioned before, the range of building or climate zones, I should say, range from kind of a mild marine climate the Northwest to some sites in Northern Minnesota with much more demanding continental climates. Next slide, please. Let's see. I think Rose – I can't remember – but I'll introduce Adria. Adria Banks is one of our primary analysts at Ecotope, and she did an amazing job going through the Mount Everest of data and making sense of them. And I'll let her describe what happened.

Adria Banks: Great. Thanks, Bob.

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So as part of the section of the presentation, I'm going to review some summaries of the key energy characteristics that were collected during the extensive plan review and field verification effort of this project that Bob explained earlier. And so the purposes of this presentation will focus on building in common areas, so looking at thermal envelope and HVAC system, hot water systems, as well as interior lighting, and spend a little bit of time looking at the dwelling unit sampling, specifically high efficacy lighting and local HVAC summaries there. Next slide.

So I'm going to introduce a graph that's common in the report that is available online, and was standardized from the Department of Energy single family studies that Jeremy overviewed in his introduction. So that all of the characteristics are summarized in the same way.

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Along the x-axis, we have the characteristic of interest. And the y-axis is count of the buildings. Each of the climate zones are summarized because certain climate zones may have different prescriptive requirements. And the prescriptive requirement is indicated by a vertical line on the plot. There's also some summary information about the number of buildings and the average value across the sample. So this is a very common graph in the reports.

We're going to use in the following slides just as example from one of the states that sort of, overall looks like what the general spread was for the four example states. But there are summary tables for the four states, individual information below each of the plots that look like this. Next slide.

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So starting with thermal envelope, here we see Washington, wood frame ceiling U-factor information. And you're probably well-aware, multifamily buildings can be comprised of very diverse construction assembly. For many of these thermal envelope characteristics, we summarize the construction assembly with the majority area for each of the buildings, and then use that to characterize that given in this case, the thermal envelope characteristic.

So these were typically wood trusses across all four states, and in most cases, across the sample states. We did show agreement with the code requirements. So looking at that table below the plot, we have each of the states and the sample climate zones, as well the individual code requirements by state, and then the average value that was sampled as part of this project.

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And the compliance rate by state as well. So, overall, very high compliance with this thermal envelope characteristic. Next slide. The majority of buildings with above grade wood frame walls, which was the most common construction assembly were either met or were better than the prescriptive code requirements. We saw very good agreement with code requirements in this characteristic. The most common construction was 2x6 wood frame walls with sufficient insulation to meet, or at times exceed the code requirements, or better than the code requirements. Next slide.

This summary shows window U-factor. So most buildings met or were better than prescriptive code for _____ U-factor requirements.

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In some cases, buildings that did not meet the threshold had _____ U-factors that were quite close to the prescriptive requirements. For example, some site in Illinois had a value of 0.35 U-factor, which is close to the prescriptive threshold of 0.32 in that space. But, again, as you've seen thus far, overall, very good agreement with code requirements. Next slide. This is the last thermal envelope summary we'll look at. And here we see a little bit lower agreement with the code requirements across the states.

In some cases, our field teams were able to determine that alternative pathways, such as UA tradeoffs or performance-based compliance were used in some of the cases with the buildings that had higher slab F-factor value. Next slide.

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We're going to transition out of the thermal envelope realm and look at some of the system characteristics for water heating and space conditioning. That equipment meets the Federal Efficiency Standards as a result of equipment that's below that minimum standard. It doesn't tend to be available in the market. We focused on the typical fuels and equipment that's used to delivered hot water to a multifamily building.

And we're gonna look at a few tables that compare and contrast the strategies used across a four states, and use these highlighted cells that show different strategies that we're seeing for hot water. So predominately in Illinois and Minnesota, there was a large fraction of central gas boiler or large storage systems used to deliver hot water to the building occupants.

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Whereas in Oregon and Washington, they tend to be in-unit electric-resistant tanks that are distributed throughout the building. Next slide.

Rosemary Bartlett: Okay. Adria, we're going to take a brief break and ask another polling question. This relates to professions of our attendees. So I'm going to open that poll and ask folks to pick the profession that most closely aligns with yours. And I'll give me a few seconds to answer that question. The speakers coming up then we'll keep this information in mind as they're presenting. Another couple seconds to answer the question. All right. I'm gonna close the poll and share the results.

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There we go. So everybody can have a look at the attendees who are watching today. All right. Thanks very much everybody. We appreciate that. And, Adria, we're going to continue.

Adria Banks: Okay. Thank you, Rose. We were talking about domestic hot water. Here, these summaries look at common area heating and cooling system, and we observe state differences in the strategies used for those common areas. This was a subset of the buildings. As Bob mentioned, we had common entry and garden-style buildings. These summaries are limited to common entry buildings that have shared interior common areas that would be conditioned. Much like with the service water, we saw electric heating strategies being common in Washington and Oregon, with Oregon using a bit more split system heat pump equipment…

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For cooling strategies, mainly split system heat pump and package terminal air conditioning. So those are packaged terminal being conducted and installed through a wall cutout. As noted, in Washington's climate, it's currently mild enough that even the common entry buildings, cooling systems were uncommon or not prevalent for common areas. Next slide, please. As with those common area heating and cooling strategies, we also looked at interior lighting of common entry buildings. And these tables show overall fairly high agreement with the code requirement for both corridor and stairwell lighting power density values.

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Next slide, please. So we're going to transition now to a few summaries from dwelling unit samplings, specifically high efficacy lamps and the heating and cooling and conditioning strategies found in the dwelling units themselves. So high efficacy laps, it's not a code requirement in all of the states. Oregon doesn't include that and their energy code requirements, but it is a common threshold across Illinois, Minnesota, and Washington to require 75 percent high efficacy lamps.

Because of particular characteristics, we found across the board, and including in Oregon, a very high level of high efficacy lamps installed in these new construction buildings and the dwelling units. So across the board, over 90 percent of high efficacy lamps were used. Next slide, please.

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So as of building condition strategies, we're looking here within the dwelling units, themselves, and we do see a fuel split as we did earlier. The gas furnaces were very common in Illinois and Minnesota with electric resistance being more common in Washington and Oregon with some heat pump equipment contributing almost equally to Oregon along with their electric assistance. Next slide. So here we have the cooling systems, and we do have overlap in the strategies that were used across the state there with commonly having non-ducted packaged terminal air conditioning air strategies, as well as split system ducted systems…

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…and a lot of split system and packaged systems used in Oregon as well. Also, _____ in Washington State, currently, the climate is mild enough that we didn't observe a high number of cooling systems installed for dwelling unit conditioning. With that, I will pass the presentation to my college Scott Spielman. Rose, next slide.

Scott Spielman: Great. Thank you, Adria. I'm an engineer also at Ecotope, and I was responsible for much of the energy modeling and analysis portion of the study, which we'll discuss in the next few slides. The first thing I'll discuss is that energy use analysis.

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Here, we estimated the annual energy use of each building surveyed to create an expected EUI range for low-rise and multifamily buildings in each state. EUI, as some of you already know, is the energy use per square foot. It's a useful metric for comparing energy use in different-sized buildings. We use PNNL prototypes as a starting point to create four different seed models. The seed models included common entry and garden style layouts as Bob mentioned earlier in the presentation, and those were combined with and without a basement.

For each building surveyed, a seed model was chosen that best represented that building's geometry, and then key inputs were altered in those seed models, including all the characteristics that Adria just discussed…

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…envelope components, lighting, power, density, and mechanical, and hot water systems to create 95 individual models to represent the buildings. Simulation results were used to generate EUI ranges for those surveyed buildings, and results also allowed us to understand the end uses; heating, cooling, hot water, lighting and plugs, and how those end uses changed due to the characteristics and climate. Next slide, please. This slide shows a EUI histogram with each state represented by a different color. And each climate zone is represented by a different shade of color if the state includes more than one climate zone.

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Histograms for each state represent the EUI range that can be expected in those states based on the building surveyed and the modeling methodology. Due to the relatively mild climate in Oregon and Washington shown here in green and blue, those states have a lower EUI range centered around 30 EUI. Illinois and Minnesota, which are shown here in purple and red have colder climates, and their EUIs are centered around 45 and 50 respectively. Also note, there's a higher EUIs in Eastern Washington, which is represented by the light blue climate zone 5B because of its colder climate.

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Next slide, please. As part of the energy use analysis, end uses were also assessed. End uses were broken down as shown in the plot shown on this slide by cooling, heating, fans and ventilation, lighting, hot water, and appliances, and equipment. This figure shows the modeled energy's breakdown for each of the buildings surveyed in Illinois. But the report has a similar plot for all four states. Hot water and heating showed the largest variability and potential for savings. Heating was affected by both the chosen mechanical system and the envelope performance, whereas hot water was affected by the hot water system only.

[0:49:00]

Next slide, please. So the second part of the modeling analysis was the measure analysis. And it was used to quantify the energy and cost savings for bringing and envelope and lighting components up to code compliance at a state-wide level. Findings were extrapolated to state-wide level using surveyed buildings as a representative sample. Next slide, please. During the measure analysis, the performance map like this one shown on the slide were used to estimate savings for individual components. To create these performance maps, a baseline model was run through a range of values for an individual component.

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The plot on this slide shows the results for ceiling U-value. So this is showing a baseline value run through a range of ceiling U-values from less than .02 to above .06, and then plotted along the y-axis is EUI. And the energy savings from the building survey could be estimated using the overlay histogram which is shown in light yellow there. This would estimate the savings from all the buildings in the state. Next slide, please.

[0:51:00]

State energy and cost savings were then extrapolated to statewide-level using census data to determine the total number of units in the state. The table above in the slide here shows the savings for Illinois. As shown on the table, exterior wall U-value has the most opportunity for savings should every building be brought up to compliance. These are the savings left on the table as Jeremy mentioned earlier. However, relatively good compliance, which

Adria discussed was seen in all states, so there wasn't an enormous amount of savings opportunity found. Next slide, please.

[0:52:00]

So just to summarize, most building surveyed met or exceeded code resulting in little savings in the measure analysis. And climate mechanical system type and hot water system type had the biggest impact on modelled energy use. And this last bullet here, high efficiency lighting was common. Great. Next slide, please. Yeah, so I'll pass it along to Scott Pigg to discuss the market research study.

Scott Pigg: Hi, everybody. Yeah, so I'm just gonna take a few minutes to walk you through the top line findings from the market research task. And as Jeremey and Bob both mentioned, you know, low-rise multifamily kind of fits into this strange category that's kind of residential, but kind of commercial.

[0:53:00]

And so going into the project, I think there was a lot of curiosity about who is it that constructs these kinds of buildings. So we did some work on that. And then while we're out asking about the characteristics of these firms, we also wanted to get some information on just about knowledge of the residential code, availability of code training, and perceived needs for code training. So the way we went about it was kind of two things. One is we sent out closed-end survey to more than 800 firms, and these were all folks that were part of the recruiting process for the fieldwork. So, you know, for every site that actually participated in their study, there were many that we reached out to try to recruit.

[0:54:00]

And, often times, they didn't have any properties for the study, but they were sometimes willing to talk to us about the market research task. And so was a combination of developers, A&E firms, contractors, facility managers, and others. And then the second part of it is that we targeted about 25 interviews to code officials and other kind of key players in each one of the states. Next slide, please. So, yeah, we reached out to 800 individuals for the survey. We ended up getting 44 responses despite, you know, making repeated e-mail and phone requests for respondents.

And I wish we had time and had thought of like putting some of our survey questions into this webinar. Because if I wrote down that polling question, right, about half are in A&E firms, and we could have tripled our sample size just by having one polling question on one of the things we were interested about.

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But among those survey respondents, it mostly developers, A&E firms, general contractor, but we did have a few HVAC contractors and other subs. In geographic reach of the firms of our survey respondents, they were mostly working within a single state. Some were regional, you know, within two or maybe three states, but a few were larger national firms. And then we had quite a variety of construction delivery methods that people were using for their low-rise multifamily construction, which I won't go into here in the interest of time.

Over on the interview side, we're mostly talking to local code officials, but we did do some interviews with like state code official folks and a couple of folks that are involved in like our test third party testing and verification. Next slide, please.

[0:56:00]

So one of our big questions was who is it that, you know, builds low-rise multifamily. Is it like mostly single-family builders that are moving over and building, you know, the slightly bigger multifamily building? Is it firms that mostly work on mid and high-rise multifamily or commercial buildings, and are, you know, sometimes move down and build those smaller low-rise multifamily. And the answer seems to be all of the above. So we asked each respondent how much of their business came from each one of these building types. And for example, you can see for single-family homes, on average, our respondents said that 13 percent of their buildings – of their business was single-family construction. But that ranged among the individual respondents from none to 70 percent.

[0:57:00]

So on the 70 percent side, so we do have some folks out there that mostly builds single-family home, but occasionally cross over and do some low-rise multifamily. Similarly, we've got – on the other end, we've got an average of 20 percent respondent businesses commercial buildings, but that again ranges from 0 to 70 percent.

However, I think you can see kind of in the middle that probably the majority of the work is done by firms that mostly focus on low-rise multifamily or maybe larger mid-rise multifamily.

And another thing that we found out is that most of our respondents work at firms that don't do a lot of – they're not large firms. They're doing fewer than 10 projects per year. Next slide, please. When we asked about knowledge and needs regarding residential code, the big thing that cropped up was that in two states…

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There's like clear confusion about which code applies in what situation within low rise multifamily. And it gets kind of tricky where, you know, if you have one-story of commercial topped by two floors of residential, you know, I think most of the code interpretation would be the first floor is treated as commercial code, but the upper two floors are subject to residential code. But we found respondents telling us, "No, it should all be commercial code." Or another situation is when you have underground parking topped by three floors of residential. There are differing answers about which code is applicable. Most of this mostly seemed to be cropping up in Minnesota and Oregon, and less so in Illinois and Washington.

[0:59:00]

And then what we found is that, you know, most of the respondents, you know, got most of their information about code or their knowledge about code directly from the code officials that they work with or from online resources. We found developers mostly saying that they mainly rely on their general or subcontractors to know the code and make sure that the building is up to code. Architects felt like they were had a pretty good handle on the code that applies to them.

You know, oftentimes, they're very knowledgeable about the shell requirements for code, but the mechanical system stuff is something that they just rely on HVAC subcontractors to know. The survey respondents did identify some issues with understanding and complying with codes, but some are contradictory to that. They said, well, but they're not really that interested in having more formal code training on it.

[1:00:00]

The code officials that we talked to generally felt like the code what was reasonably well-followed in this space of low-rise multifamily. The issues that they've identified most frequently had to do with the air leakage and duct leakage code requirement and the testing requirement. And we got some real interesting answers about how variable the testing requirements are. They do vary from state-to-state, but we also had some people telling us that those testing requirements vary from jurisdiction-to-jurisdiction.

And one tester that we talked to said that they need to call each jurisdiction before they go out and test a building because you know different code officials have different requirements for how the testing actually needs to take place. Okay. So that's a quick recap of the market research.

[1:01:00]

Now, I'll turn it over to Dave Bohac, and talk about air tightness testing.

Dave Bohac: Okay. Thanks, Scott. First, I'd like to thank everyone who helped with this effort, specifically Gary Nelson and Kyle Nelson with the Energy Conservatorium, and Bob Davis met with me on a regular basis to work through the data analysis. And Stewart Dials with NISS provided the initial energy plus content model that we used for energy and airflow simulations. So as Scott was saying, you know, the market study confirmed code officials and others indicate that the envelope air leakage testing requirement can be a significant compliance issue.

And that's partly due to the ambiguity of the code requirement that states, and I'll quote, "The building or dwelling unit shall be tested." So for single-family homes, that's pretty straightforward, but what does it mean for multifamily buildings? Should be testing the entire building or individual units?

[1:02:00]

And if we test individual units, should we focus on the exterior leakage or the total leakage, that includes both the exterior and the interior. So, you know, how we test has an enormous impact on the results. For example, in Minnesota, common entry buildings, the average whole building leakage was 1.2 ACH-50 while the average total leakage for individual units was 3.4 ACH-50 or almost three times greater. So there's a big difference on your results by what you test. So due to the ambiguity in the testing requirements, we decided to do a deeper dive into the issue of envelope leakage testing.

We conducted tests on 25 buildings in six states. That included Oregon, and Washington, and the Pacific Northwest, Minnesota, Illinois, Iowa, Michigan, and the Midwest. And then for each building, we included three different tests. One, the whole building exterior leakage. Two, the compartmentalization test of an individual unit for total leakage. And then three, a guarded test of individual unit exterior leakage.

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So, overall, our judges objectives were to, one, compare the results for the different test methods, and then also try to identify which variables had the greatest impact on leakage. And we wanted to establish a protocol that could be used for future studies if they wanted to do the same thing. And then we evaluated the energy impact on envelope leakage both interior and exterior. And then we were interested in providing guidance on the air leakage test method for low-rise method for low-rise multifamily buildings.

So we succeeded in collecting an enormous amount of valuable leakage data. The 350-page final report includes over 125 tables and almost 250 figures. But, you know, the best method for how to test multifamily buildings is still an open question, and that's partly because it depends on your criteria. So next slide, please.

[1:04:00]

So in this of presentation, I'm only going to be able to provide highlights of our results I'd encourage you to kind of dig into the final report when it becomes available. And sometime in the future, we're looking at providing a webinar that will just focus on the early leakage test results for those of you that's, you know, your primary interest. Then I'm gonna start out here talking about the results from the whole building tests. So these two diagrams show the set up for the test.

For garden-style buildings, which is shown in the left, that test is performed by putting a blower door in every unit and conducting a 50 Pascal Depressurization test simultaneously on every unit. That way there's no airflow between the units. There's no interunit are leakage. And the sum of the vorgar flows is the whole building exterior leakage. So for common entry building shown on the lower right, use one or more fans in the entry. So an exterior doorway, you open up all of the hallway doors for the units so that pretty much you have a single zone.

[1:05:00]

And then that way the sum of the vorgar flows is equal to the exterior leakage. Next slide, please. So this chart shows the whole building results. The format is the same as what Scott had shown previously. The black vertical lines show the leakage requirements for each state. Values to the right indicate that the building was in compliance. And the common entry buildings are green, and the garden style are blue. And the averages for each state are shown over to the right.

So the good news is that there was 100 percent compliance based on the whole building test. Only three buildings for greater than three ACH-50, and the average was 1.6 ACH-50. So the average was lowest in Minnesota, which might be expected since it had the lowest code requirement, and Washington had the average – or the highest average. The lowest for an individual building was .4 ACH-50 for a passive house certified building in Illinois.

[1:06:00]

So if we go to the next slide, please. So normalizing the leakage at 50 Pascal with the building volume to compute ACH-50 or air changes per hour at 50, that's been the standard practice for single family houses. However, for larger buildings, it's a lot more typical to normalize by the envelope surface area. So this chart shows the whole building leakage at 50 Pascals normalized by the envelope exterior surface area.

So for this, the average was .23 CFM-50 per square foot. And 83 percent of the buildings were below .3 CFM-50. A useful references that army corps uses a requirement of .25 CFM at 75 Pascals per square foot of envelope area, which is about equal to .19 CFM per square foot. So about half of the buildings met the army corps leakage requirement.

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Next slide, please. So we were interested in identifying what building and design characteristics were having an impact on the building leakage. We compiled information on the code requirements, roof or attic type, any energy program leakage requirement type of space below the lowest occupied level and air barrier design. So we evaluated the common entry in the garden style buildings separately. Next slide, please.

So for the common entry buildings, we conducted regressions of the variables with the whole building leakage. And we found that the type of attic and the code required leakage had a significant impact on the measured building leakage. So this chart indicates the code required leakage on the horizontal axis, and the whole building leakage on the vertical axis. So the buildings with flat roofs are indicated by the blue symbols down lower, and the vented attic buildings are in red.

[1:08:00]

So you can see the significant difference between the buildings by attic type. The vented attic buildings are consistently leakier than those with flat roofs. And there's generally a good relationship between the code required leakage and the measured leakage. And then the passive house certified building was a low outlier. So it was kind of interesting that the energy program requirements, the space below lowest occupied and the type of exterior air barrier did really not correlate well with the building leakage. Next slide, please.

So let's move on to the leakage results for individual units. These diagrams show the set-up for compartmental station testing. That measures the total leakage of an individual unit, so this includes both the exterior and interior leakage. This test was really similar to conducting a vorgar test on a house, but it's just for an individual unit. It has only one unit at a time and you get the total leakage of the unit. probably catch of the unit. Next slide, please.

[1:09:00]

We also conducted a guarded test to measure only the exterior leakage of the unit as shown in the upper left. For garden style buildings, this is really the same as the whole building test. Since they're all being tested simultaneously, there's no airflow between the units, and blower door flow for each unit measures the exterior unit – or the exterior leakage just for that unit. The challenges are that you need a blower door for every unit. So if you've got a 16-unit building, that means you've got 16 blower doors that you need. And the test needs to be coordinated to make sure you're doing simultaneous measurements.

For the common entry buildings, the guarded test is a combination of the whole building and compartmentalization tests. A diagram is shown to the lower right. The use the fans in the building entry, and you open up all the hall doors like you do on the old building tests to depressurized the entire building to 50 pascals. And then at the same time, you put blower guard in the hall door of the test unit…

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…and you adjust the flow rate so there is no pressure induced between the test unit and the adjoining units. So with that approach, the blower door is simply measuring the exterior air leakage for the test unit. Next slide, please. So here’s some high-level results for the total in external leakage for individual units. The information on the left is for common entry buildings, and on the right are results for the garden style buildings. The chart shows the cumulative distribution of the percent of exterior leakage for each unit.

While some people might be comfortable with this plot; others, not so much. And the green symbols are just the exterior leakage divided by the total leakage or percent of external leakage. And that’s on the horizontal axis, and the number or percentage of the units is on the vertical access. And then up about are the average leakages and the average percent exterior leakage. Those are above the charts.

[1:11:00]

So for the common entry buildings, you can see that a quarter or 25 percent of the units have a percent exterior leakage of 22 percent or less. The median is 28 percent point, and a quarter of the units have a percent exterior leakage greater than 39 percent. So the distribution is pretty tight, tighter for the first time 75 percent of the units and then it has a wider distribution on the top 25 percent. In general, that’s because the units on the top floor of the vented attic buildings have a higher exterior leakage, and they’re the cause for that wider distribution in the top 25 percent.

And it showed previously that they the vented addict buildings had higher leakage. Compared to the common entry buildings, the garden style buildings, those results are shown on the right. So they had higher exterior total leakage. They were about two times leakier than the than the common entry buildings. And then in addition, the percent exterior leakage is higher.

[1:12:00]

So the percent exterior leakage for the garden style buildings was about 50 percent compared to 34 percent for the common entry buildings. So I guess that will bring us to our polling question.

Rosemary Bartlett: Yes, let's very quickly do our polling question related to if there's any particular area you would be most interested in getting more information about, and if you would select that. A couple more seconds. Okay. Thank you very much. I'm gonna close that and I'll share the results. It looks like particular interest in more information about building characteristics and air leakage, and some for market research. Okay. Great. Thank you very much everybody.

[1:13:00]

Dave Bohac: I guess we can go on to the next slide.

Rosemary Bartlett: Well, it's showing for me, but not showing for anybody else.

Dave Bohac: *[Laughter]* I'm going to start my intro to that slide. So the compartmentalization test for total leakage is commonly used to measure the wreckage of multifamily units. So, however, it's expected that the exterior leakage of the unit has the greatest impact on air filtration and space conditioning loads. So for an energy standard or requirement, it might make sense to only focus on the exterior leakage. So you can do that with the guarded test, but they are significantly more challenging than the compartmentalization tests for total leakage.

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So the question is can you use the total leakage measurement with other information to estimate the exterior leakage? Ah. There we go. So one approach is to multiply the total leakage by the exterior envelope surface area, and then divide by the total surface area. So that works well if the relative leakage of the exterior and the interior is about the same but what we were finding is that this approach doesn't really work that well. So the chart to the left shows the relationship between the measured external linkage on a horizontal access and the calculated exterior leakage on the vertical axis.

And then the bar chart on the right shows a histogram of the percent difference between the calculated and measured leakage.

So for our buildings, the calculated exterior leakage was within 25 percent of the measured value only 18 percent of the time. And for 31 percent of the units, the exterior leakage was overestimated by more than 50 percent.

[1:15:00]

And for 14 percent of the unit's leakage was under estimated by more than 50 percent. So this isn't a very accurate estimate for most units, at least not for the buildings in our example. So I don't have time to show our results, but we developed a method to have a multiplier that was used. It was based on the building type level and the building type of attic, and that provided a much better estimate of the exterior leakage with the total leakage. And it worked fairly well across all the various buildings.

However, if you're gonna apply this to another set of buildings, you really want to do similar types of measurements to confirm that that relationship holds. And the relationship isn't going to hold if the builder decided that they're going to focus on tightening up the exterior envelope versus the interior envelope. We also worked on a method for garden style buildings to use a pressure measured and adjoining units during the compartmentalization test.

[1:16:00]

I'd say that approach shows some promise, but it needs more work. So if you want to continue onto the next slide. And I think we'll go ahead – I'll just say we also looked at the impact of the common space exterior leakage for the common entry buildings. I'll just say that, overall, the common areas for 70 percent leakier than the residential units. And for seven of the 20 buildings, the common area was more than twice as leaky as the residential units. And on average, the common area leakage was made up about 29 percent of the total leakage in the building. So ignoring that certainly ignores a lot of air leakage in the building and the energy use in the building.

Okay. We'll go to the next slide. So just to kind of summarize things. Again, the whole building procedure tends to be equipment and labor intensive, especially for garden style buildings.

[1:17:00]

All of the buildings that we measured met the state-required leakage levels for the whole building leakage. We found that the type of building, roof type, and the code required leakage had significant impact on the measured leakage. Not so much for the other variables that we looked at the common areas. The common areas were significantly leakier than the residential units, and they have a significant impact on the whole building leakage.

The percent exterior leakage was averaged 34 percent for the common area of buildings, 54 percent, somewhat higher for the garden style. Those are median or average values, and that the surface area ratio method tends to be a poor predictor of the exterior leakage when you're applying that from the total. Next slide, please. So as I mentioned, it's quite a long final report. I just try to hit the highlights here.

[1:18:00]

The final report includes a number of other interesting findings. Again, I talked about the exterior of – or the accuracy of using a multiplier to convert the total leakage to exterior leakage. A method for using the adjacent unit pressure difference for garden style units to go from the total leakage to the exterior. We also have a breakdown of the exterior leakage to the common space and adjoining units. We looked at the impact of do you keep adjoining units open or closed for compartmental station testing.

Looked at the variability of the measure leakage for units within a building and on the same floor that may help with the issue of how much you need to sample or how many units you need to sample to get a good measurement. And then we looked at the number of fans that were needed for whole building tests. And then there's a very extensive section there where we did modeling of air leakage at the energy penalty with different levels of interior and exterior leakage and ventilation systems.

[1:19:00]

So, basically, we did energy use simulations. And then to wrap things up, some ideas for future research. And we're getting short on time, so I'll kinda leave that there, and then I think we need to move onto Q&A.

Helen: Okay. Thanks, everyone. Great questions coming in. We have just shy of 10 minutes to do some Q&A. So I'm going to direct the first question to Adria. This is about building characteristics. And there was some specific questions, but this one is about above-grade walls, that wall framing factors in multifamily is frequently quite high. Was this detail considered when you were assessing wall compliance?

Adria Banks: Great. Thank you.

[1:20:00]

The wall framing factors were measured through looking at the construction assembly of the walls, so what materials the wall was made up with, as well as a variety of insulative components, be that sheathing, or blown in batts, etcetera. And that that information distilled down to a U-factor for each of those wall types or assemblies. We then took by wall construction type, a weighted value, a weighted average value across the area, wall area, for that building.

So to dispel it down to the major area for each building that was of that given wall construction, and what that weighted U-value was for the building to look at that at that against the compliance values for each space.

[1:21:00]

Helen: Okay. Thanks, Adria. And a follow-on question on the building characteristics: "Did you look at how many required and reviewed heat gain and loss calculations, equipment sizing, and duct design plans, was that part of –?"

Adria Banks: No, that's a great question. So as Bob mentioned, and I think I did as well, we did a lot of drawing review, plan review, and then that was followed by field verification. We also requested or reviewed, if they were available, things like energy code submittals, manufacturer specifications, either onsite or online for equipment. O&M guides and O&M manuals if those were available on site, as well as permit submittals. I will say of those resources that I just listed, they were not frequently available to us. So most of the assessment was done from those drawing and our own onsite field verification.

[1:22:00]

Helen: Okay. And one last question about building characteristics in terms of domestic hot water. There was a question about what the percentage that was reflected in the slide referred to. Can you respond to that?

Adria Banks: Oh, absolutely. I may not have set those tables up as well as we transitioned into the water heating and space heating systems, but those percentages are that percentages of building that had that given water, in this case, water heating equipment and fuel strategy. So each of the states were distributed across those central gas or in-unit gas, in-unit electric strategies for water heating. And that would reflect the percentage of sample buildings that used that given, in this case, water heating strategy.

Helen: Okay. Thanks, Adria.

[1:23:00]

The next questions are for Scott Spielman on energy use analysis. The question is: "Were is the energy models in any way compared to our calibrated with actual energy use data from the sites?"

Scott Spielman: We were not able to collect billing data from all the site survey, so they were not calibrated to electrical and gas data. But Ecotope has a lot of experience calibrating other multifamily buildings, and we definitely considered how our other calibrated buildings related to these buildings, and used that to make determinations that the results were in line with what we expected from our experience.

Helen: Okay. Thanks, Scott.

[1:24:00]

And another question about energy use analysis: "In addition to savings relative to state current code, did you look at either savings relative to recent model code ICC-2018, or savings relative to the best performers in your state samples?"

Scott Spielman: We did – we looked at the code that was used when the building was built, so we didn't compare it to the more recent code. We only compared to the code that was used for that building to be constructed. And as far as comparing to the best performers in the sample, we definitely looked at the different building characteristics that allowed for a building to be more or less efficient and *[inaudible due to audio cutting out]* …

[1:25:00]

…compared them to the average as the lower performing buildings. And in the report, there's some discussion on if that was able to perform better than others.

Helen: Okay. Thanks, Scott.

Scott Spielman: I hope that answers that question.

Helen: Thank you. And I think we probably have room for one more question, and I'm going to direct this to Dave Bohac on air leakage. Does a leakage test based on an individual unit compartment leakage make any sense?

Dave Bohac: I mean, yes, I think it does. I would say it's fairly standard practice to do tests, compartmentalization test of individual units.

[1:26:00]

And I know it includes both the interior and exterior. But many times, you know, the interior leakage is also an important kind of performance criteria if you're interested in air flow between units and contaminate transfer, if you're looking at the effectiveness of ventilation systems. Yet, you know, interior leakage has an impact.

And when we did our energy modeling studies with Energy Plus and CON-TAM, I was surprised to see that there's cases to where the interior leakage does have a significant impact on energy consumption that doing a compartmentalization so the units are – you know, don't interact with their neighbors very much helps to reduce our infiltration and energy costs.

Rosemary Bartlett: Great. Thanks Dave. Appreciate that. I would like to thank all of the speakers today.

[1:27:00]

And Helen thanks very much for moderating the Q&A section. I'd also like to put in a plug for our other upcoming webinars. We hope that you'll be able to join us Thursdays at 1:00 p.m. Eastern to keep this great conversation going on these various topics. And thanks to everybody for attending.

[End of audio]